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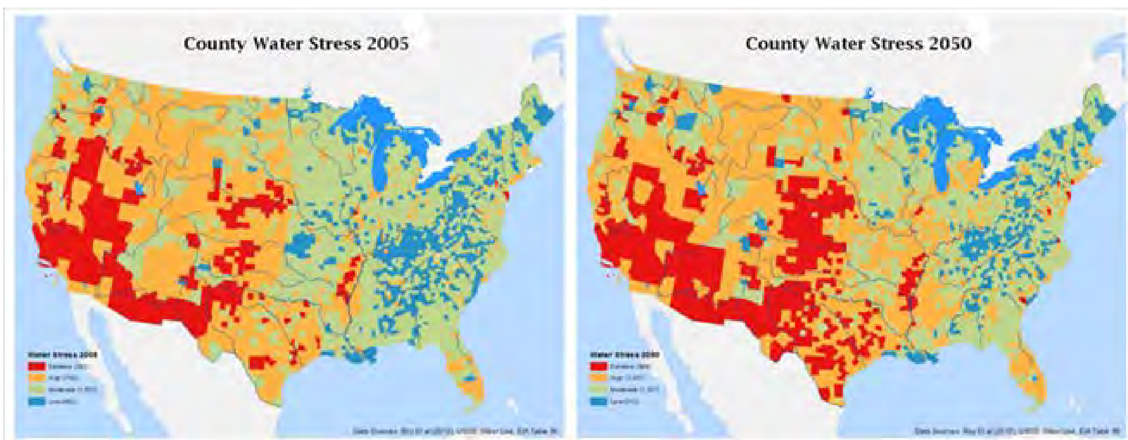
Integrated Climate Assessment for Army Enterprise Planning

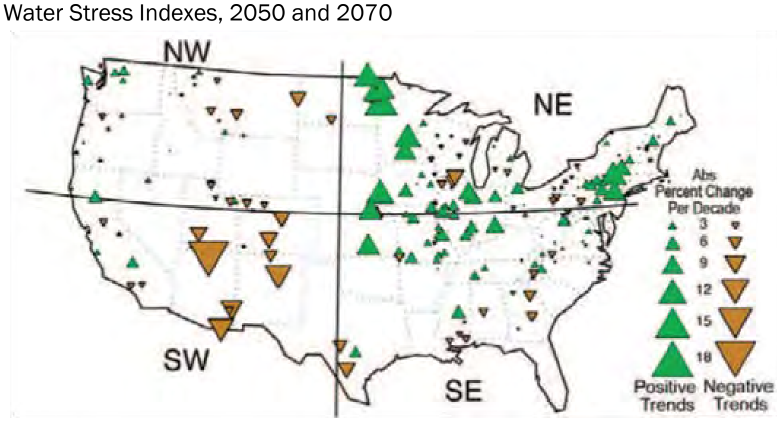
Climate Change Impacts on Water and Energy for Army Installations

James Miller, Juliana Wilhoit, Kristina Tranel, and Laura Curvey

September 2015



Water Stress Indexes, 2050 and 2070



Century-Long Flooding Trends

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Construction Engineering Research Laboratory

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Final Report

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Abstract

In the decades to come, climate change is expected to impact the Army's costs, its abilities to train and maintain the force, and its mission capabilities. These potential climate change impacts need to be considered in the Army's stationing/restationing analysis process to ensure that future decisions concerning locating and relocating Army Forces are optimized to minimize costs while maintaining the ability to effectively train, maintain and deploy forces.

The Center for Army Analysis (CAA) is part of the Army Stationing Process that is responsible for analyzing and recommending possible stationing scenarios to Army leadership. In the past, environmental considerations were not well defined and were treated in a qualitative rather than quantitative manner. As a result, CAA recognized a need to focus on environmental issues, particularly the effects of climate change on future stationing actions. This study was performed to identify and recommend possible improvements to the Army's stationing/restationing analysis process, specifically, by including climate factors in the stationing analysis process to enable a more complete modeling and cost analysis.

Executive Summary

Background

Over the years, the needs of the U.S. Department of Defense (DoD) change, often resulting in an excess of facilities and installations that are no longer wanted or needed. Until the 1960s, DoD enjoyed wide latitude in disposing of unneeded facilities. This relative freedom ended in the 1970s when base closures were largely halted. During the 1980s under the Reagan Administration, the institution of "BRAC 88" temporarily reinitiated the Base Realignment and Closure (BRAC) process to overcome the political hurdles associated with BRAC impacts on various constituencies. The '88 DoD BRAC Commission reported to the Secretary of Defense, who forwarded the recommendation package to the President for approval/disapproval in its entirety. On presidential approval, the package was submitted to Congress for their approval/disapproval in its entirety.

Although BRAC 88 was begun as a one-time action, subsequent BRAC rounds were conducted in 1991, 1993, 1995, and 2005. No BRAC rounds have been initiated since 2005. BRAC 2005 differed significantly from previous BRAC rounds in that:

- It included a stable or increasing force structure (no drawdown).
- It was undertaken in a new threat environment (current ops and post-9/11 environment).
- It placed a major emphasis on military transformation.
- It established a 20-year Net Present Value (NPV) cost horizon.
- A $21B budget "wedge" was established
- Headquarters and Support Activities Joint Cross-Service Groups (HSA-JCSGs) were given an independent point of entry into the process. There was significant overlap between the HSA-JCSGs.
- HSA-JCSG was chartered to merge Business Process Reengineering with traditional BRAC. HSA-JCSG had no counterpart in previous BRAC rounds.
- It recognized the need for integration with the military department (MILDEP) teams.

Such base realignment decisions have very long term consequences; decisions regarding base realignment must consider resources for many years into the future. The process, based on the last major stationing action

(BRAC 2005), is as follows. When DoD considers stationing or restationing of Army Forces, the Army engages the support of the Center for Army Analysis (CAA) within the HSA-JCSG to consider a number of critical attributes of installations and to perform the required analyses to determine what gives specific installations military value (MV). CAA interviews Senior Leaders and consults with subject matter experts (SME) to determine the MV attributes (MVAs) that will be examined in the MVA analysis process (Criteria 1-4 below). Although there is flexibility as to which metrics are examined, the analysis is bound by congressional mandate to examine eight criteria:

1. *Criterion 1*. The current and future *mission capabilities* and the impact on *operational readiness* of the total DoD force, including the impact on joint warfighting, training, and readiness.
2. *Criterion 2*. The *availability and condition of land, facilities and associated airspace* (including training areas suitable for maneuver by ground, naval, or air forces throughout a diversity of climate and terrain areas and staging areas for the use of the Armed Forces in homeland defense missions) at both existing and potential receiving locations.
3. *Criterion 3*. The *ability to accommodate contingency, mobilization, and future total force requirements* at both existing and potential receiving locations to support operations and training.
4. *Criterion 4*. The *cost of operations* and the manpower implications.
5. *Criterion 5*. The extent and timing of *potential costs and savings*, including the number of years, beginning with the date of completion of the closure or realignment, for the savings to exceed the costs as predicted by a Cost of Base Realignment Actions (COBRA) model.
6. *Criterion 6*. The *economic impact* on existing communities in the vicinity of military installations.
7. *Criterion 7*. The *ability* of the infrastructure of both the existing and potential receiving communities to support forces, missions, and personnel.
8. *Criterion 8*. The *environmental impact*, including the impact of costs related to potential environmental restoration, waste management, and environmental compliance activities.

Current Optimal Stationing of Army Forces/Military Value Analysis (OSAF/MVA) process

Based on its experiences in a series of BRAC actions from 1988 to 2005 and other Army stationing activities, CAA developed an analytical process to optimize its stationing decisions based on costs and military value. CAA is constantly updating its process and running stationing models.

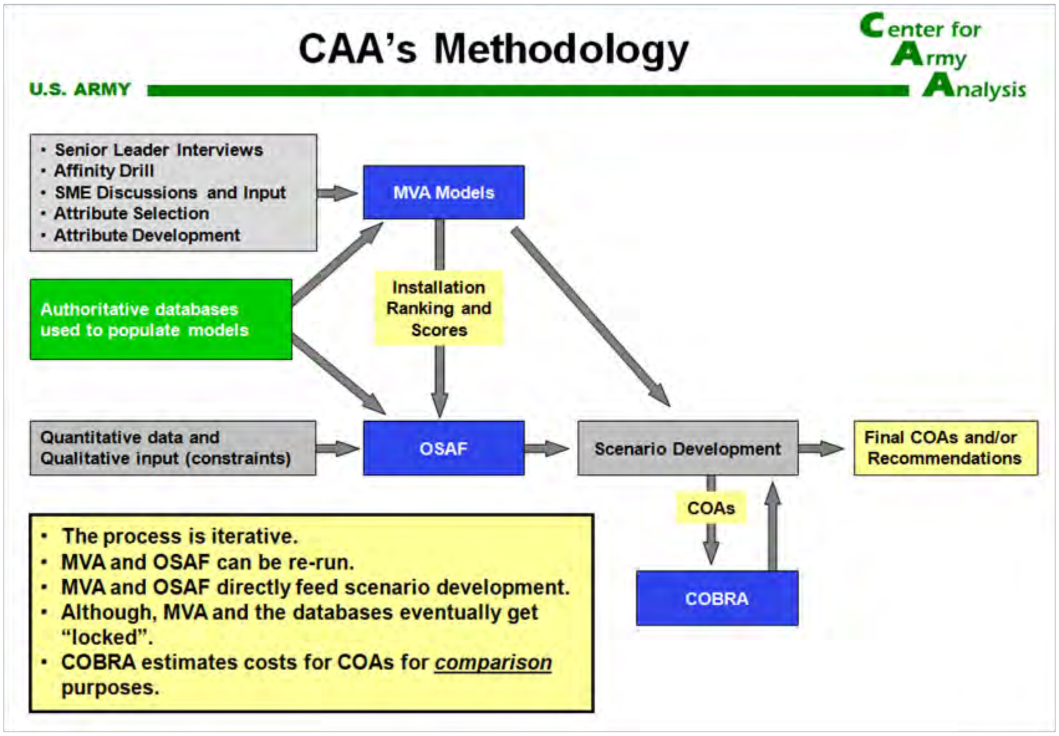
The BRAC analysis was composed of four subprocesses:

1. MVA modeling
2. Evaluation of the Optimal Stationing of Army Forces (OSAF)
3. Evaluation of the COBRA
4. Formulation of final Courses of Action (COAs) and/or recommendations.

Currently only MVA is modeling is used. However CAA plans to use these four parts in the future (Figure ES-1). This iterative process builds on MVA models as follows:

1. Capacity analysis provides a measure of an installation's available assets (supply) and the installation's capability to meet a unit's requirements (demand) in terms of measured assets.
2. Then MVA is a primary consideration in making closure and realignment recommendations
3. Installation Priority is a step in which the analyst considers BRAC Objectives, input data, capacity analysis results, and Military Value of Installations results to determine a starting point for installation analysis. The starting point represents the subset of installations where the analyst will first attempt to conduct BRAC actions.
4. Unit scenario development: installation analysis results start the "unit level" analysis. Each unit on an installation with lower MV is considered for stationing on an installation with higher MV and at locations where the Army can take advantage of excess capacity.
5. The "unit priority" step then establishes the possible installation-unit combinations when restationing units.
6. Cost analysis (COBRA) and other factors (environmental, economic impact on local communities, etc.) are then considered when recommending stationing actions.
7. Based on all these steps, multiple review boards approve, change, or disapprove recommended stationing actions.

Figure ES-1. Current CAA stationing decision analysis process.



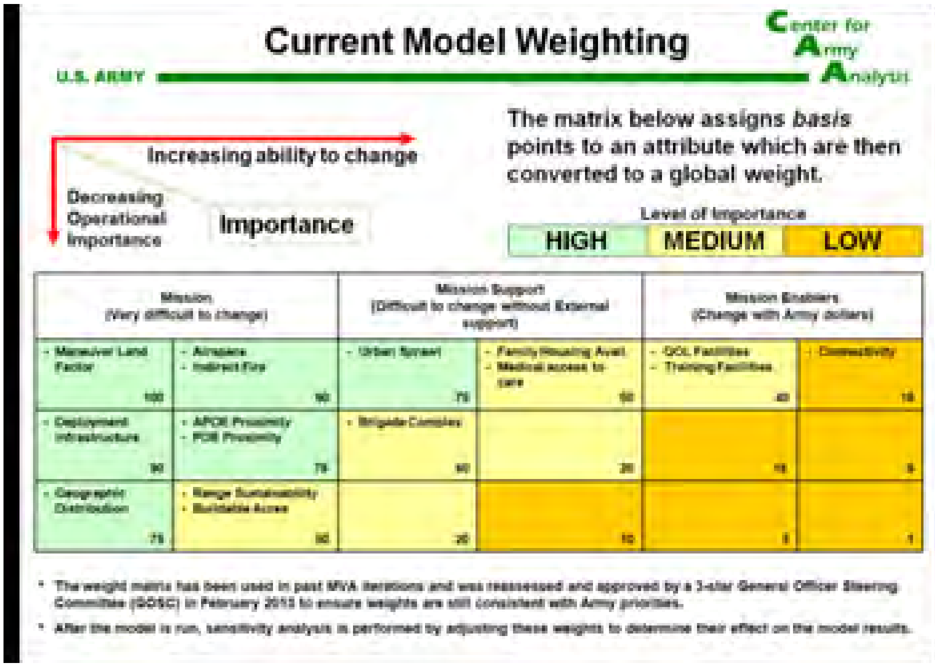
MVA modeling

MVA is a process of determining the Military Value of Installations based on a set number of attributes—quantifiable characteristics used in the MVA that relate to DoD selection criteria. Attributes represent the military value of an installation. Within the MVA, the attributes are weighted based on their operational importance and ease of change relative to each other. Each attribute has a specific weight, expressed as a percentage (i.e., value within the range of 0 to 1) and is calculated based on basis points that range from 0 to 100.

For example, recent stationing actions have included such attributes as maneuver land availability, housing, and water quantity. The maneuver land attribute is considered to be of high operational importance, and one that is difficult to change since additional maneuver land is not easily acquired. Consequently, the maneuver land attribute is weighted more heavily than an attribute such as quality of life facilities, which is more easily changed since it can be improved by investment. Installations receive a value for each attribute based on collected data. Individual attribute scores

are then weighted and summed to produce the installations' overall military value scores (GAO 2013). Figure ES-2 shows the weights assigned to attributes in a small-scale CAA stationing effort in 2013.

Figure ES-2. CAA MVA model weighting matrix (2013).



Evaluation of OSAF

OSAF was the only BRAC model that moves unit level elements that optimally takes cost into account. OSAF prescribes an optimal Army stationing solution that accounts for each unit's existing starting location, available implementation dollars, and requirements for facilities, ranges, and maneuver land and then determines where each unit should move (realign), if the unit moves, and closes installations that no longer have units.

Evaluation of COBRA

Scenarios produced by OSAF are run through the COBRA model. COBRA is a cost comparison tool used to compare stationing scenarios in terms of their 20-year NPV and payback period. COBRA allows the analyst to enter both recurring and one-time costs, such as environmental and waste management costs, for a given scenario. These values are derived from Base Operation Support (BOS) costs, which are included in the Installation Status Report (ISR).

Formulation of COAs and/or recommendations

The MVA models result in installation rankings and scores that provide input to the OSAF model using the iterative process outlined above (p v). Ultimately, this process yields final COAs and recommendations.

Opportunities for process improvement

Consideration of a longer NPV horizon

The U.S. Army operates in an environment undergoing constant change. Budgets, political considerations, international threats, technological developments, and numerous other concerns require the Army to be in a constant state of planning and preparing for future needs. Inevitably, a major question faced by Army planners deals with optimizing the stationing of Army Forces for purposes of training, maintaining, and when necessary, deployment. Army stationing is a very complex issue that rarely has an obvious solution. Decisions to station forces in one location versus another have a myriad of impacts, many of which can have effects for many decades into the future. As a result, careful analysis must identify and weigh all significant factors and impacts of Army stationing decisions.

BRAC 2005 required consideration of a 20-year NPV analysis. Since Army stationing decisions have very long term implications not only for the Army, but also for gaining and losing communities, and since the possible effects of climate change may not be fully realized for decades, a 20-year NPV analysis may no longer be adequate. A longer NPV analysis (perhaps 40 to 50 years) may be more appropriate.

Consideration of climate change impacts

Climate change can be expected to affect Army installations in at least two critical areas: water and energy. Since stationing decisions have very long term implications and impacts, it is necessary to consider possible future effects of climate change on Army installations. In the course of conducting a stationing analysis, it may become necessary to better distinguish between two or more installations that have very similar MVA scores based on Criteria 1 through 4. In making such distinctions, CAA must consider not only the abilities of existing and potential receiving communities to support forces, missions, and personnel (Criterion 7), but also the environ-

mental impact of a stationing decision, including the impact of costs related to potential environmental restoration, waste management, and environmental compliance activities (Criterion 8).

Include environmental analysis in the stationing analysis process

While the current process is useful, CAA has expressed the belief that the process may benefit from further development and improvement. In particular, in its review of the 2005 BRAC, the Government Accountability Office (GAO) highlighted that DoD's environmental analysis was incomplete. Specifically, GAO said that DoD should have given better consideration to environmental restoration of bases undergoing closure or realignment (GAO 2005, p 45). To overcome such deficiencies in future analyses, existing attributes may need to consider additional metrics. If so, there is a need to identify those metrics, to identify and locate the data available to evaluate them, and to devise a method to calculate them. A broader concern is whether there is a need to consider additional relevant attributes not yet included in the current process. Again, if that is the case, then there is a need to identify those attributes, to identify and locate the data available to evaluate them, and to devise a method to calculate them.

Although its stationing decision analysis process has worked well in the past, CAA has expressed the desire to improve the process for use in future stationing analyses. Since climate change can be expected to have an impact on the Army's costs and ability to fulfill its missions, it is in the Army's interest to include an environmental analysis in stationing decisions to enable the Army to better predict and respond to the effects of the changing climate. Army installation realignment may be affected by climate change, or it may further exacerbate problems resulting from climate change in a particular area. Stationing analyses that consider climate forecasting can recognize future uncertainties while also striving to best prepare for the consequences of climate change. The inclusion of climate factors in the stationing analysis process will enable a more complete modeling and cost analysis. To assist CAA in its effort to improve the stationing analysis process, this work aimed to:

- gather and manage a new dataset for use in other efforts
- consider possible additional attributes for the MVA model
- develop environment-related constraints for the OSAF model
- assist in specific scenario-related development
- contribute to analysis of environmental impact (Criterion 8).

Objectives

The objective of this work was to assist CAA in evaluating the current Army stationing analysis process and in responding to the critiques on the process brought forward by the GAO by focusing on the possible ramifications from Global Climate Change (GCC) on the stationing decision analysis process, specifically with respect to Criteria 7 and 8.

Approach

The project team studied the CAA stationing analysis process to gain a working understanding of the existing system. Team members sought to increase the depth of environmental (and, in particular, climate change-related) analysis in the existing MVA attributes so that an improved environmental analysis could be used in general stationing. Where it appeared that climate change might affect existing attributes, the team sought possible metrics to improve the MVA attributes. The team then sought data sources that could be applied Army-wide. When such data were available, the team developed methods for calculation of those metrics.

This project team focused on attributes and metrics associated with climate change impacts on water and energy at Army installations and facilities. In parallel efforts, other project teams considered how climate change might impact installations' abilities to deploy forces and to conduct firing and maneuver training on Army training ranges.

The first step of this approach was gain a familiarity with the CAA stationing decision analysis process. The next step was to consider the projected impacts of climate change and how they might be expected to affect Army installations. This included an investigation of existing MVA attributes that appeared to be subject to possible climate change effects. Also considered were any new MVA attributes that might merit further consideration and development. In considering any candidate MVA attributes, every attempt was made to keep the "SMART" approach in mind such that any proposed attributes should be:

- **Specific** – clear and focused to avoid misinterpretation; assumptions and definitions should be easily interpreted or explained.
- **Measurable** – can be quantified and compared to other data; should allow for meaningful statistical analysis (avoid binary "yes/no" measures – those become "screening" criteria).

- **Attainable** – achievable, reasonable, and credible under conditions expected.
- **Realistic** – fits into the models and is cost-effective.
- **Timely** – achievable within the time frame given.

After identifying relevant MVA attributes, metrics were then identified that could be used to quantitatively score installations against each other. Metrics imply the need for data, so existing data sources that could be used in calculating metrics were investigated. To be useful, data need to be reliable, credible, maintainable, and commonly available for all Army installations.

For all metrics for which suitable data were available, methods for calculation of scores for each metric were developed and documented.

Subsequent chapters of this report briefly address proposed augmented MVA attributes, their associated metrics, available data and calculation methods. More detailed discussions are provided in the appendices.

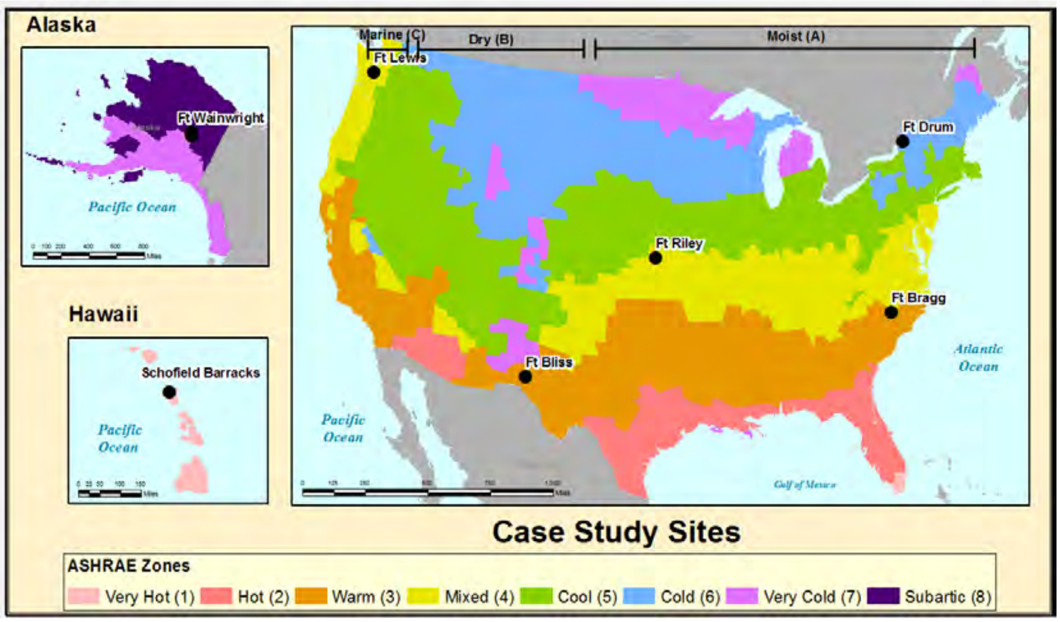
Scope

Seven case study installations that span the continental United States and are located in a variety of climate zones were selected to provide means to test the impact of climate change on the U.S. Army (Table ES-1 and Figure ES-3). All methods used in this study are scalable and can be used to assess all Army installations located within the United States.

Table ES-1. Summary of climate zone and installations

Installation	State	ASHRAE Climate Zone
Fort Lewis	WA	Mixed-Marine
Fort Bliss	TX	Warm-Dry
Fort Riley	KS	Mixed-Moist
Fort Drum	NY	Cold-Moist
Fort Bragg	NC	Warm-Moist
Fort Wainwright	AK	Subarctic
Schofield Barracks	HI	Very Hot

Figure ES-3. Spatial distribution of the case study sites in relation to their climate zones.



Project team

This project was managed and conducted by a team of ERDC-CERL researchers having a variety of backgrounds and experience in community planning, environmental and ecological considerations and installation support.

Results and recommendations

With respect to water and energy support to Army installations, it is anticipated that major climate change impacts will manifest as possible temperature and precipitation changes that will have secondary effects related to water, including:

- rising sea levels
- increased snow melt and inability of snow and ice packs to be replenished
- increased frequency and severity of droughts in some locations simultaneous with increased precipitation in other areas
- increased frequency and severity of storm events
- decreased aquifer and surface reservoir levels
- increased risk of flooding, with associated damage to infrastructure and the environment
- increased risk of wildfires, impacting training lands, utility right-of-ways, etc.

It is proposed that three existing MVA attributes be augmented and restored to the stationing decision analysis process:

1. *Water Quantity*. It is proposed that the *Water Quantity* MVA attribute be updated to include two new variables, *Water Consumption Stress* and *Water Quality*:
   a. A *Water Consumption Stress* measure is suggested as a new metric. An index of current water stress, adapted from Roy et al. (2012), was used to identify the regional water stress of Continental United States (CONUS) installations. This analysis identifies areas of existing water stress that demonstrate areas where an installation may compete with the surrounding region for water.
   b. *Water Quality* measures the amount of water on and surrounding an installation that is considered polluted (impaired) under Section 303(d) of the Clean Water Act (CWA). The proposed updated *Water Quality* MVA attribute includes impaired waterways as an indicator of degraded water quality.
2. *Environmental Elasticity*. It is proposed to update the *Environmental Elasticity* MVA attribute to include two new factors, *Renewable Energy* and *Infrastructure Vulnerability*:
   a. *Renewable Energy* measures the ability of an installation to produce renewable energy. DoD is bound by Federal mandate to reduce energy consumption, of which renewable energy is an important part.
   b. *Infrastructure Vulnerability* measures the vulnerability of installations to energy infrastructure destruction through climate-related events such as wildfires, hurricanes, sea level rise, and flooding.
3. *Sea Level Rise*. It is proposed that the following attributes be updated to include the possible impact of Sea Level Rise
   a. *Test Range Capacity MVA* attribute: The *Test Range Capacity* MVA attribute is the "combination of total square miles and the cubic airspace of test range facilities at an installation that can support test and evaluation" (CAA 2004c). It is proposed that the land that is expected to be inundated with sea water from test range capacity be excluded from the Test Range Capacity MVA attribute.
   b. *Buildable Acres MVA* attribute: The *Buildable Acres* MVA attribute assesses the ability of an installation to gain additional force capacity by expanding the facilities on site. It is proposed that the land that is expected to be inundated with sea water from the amount of buildable acres be excluded from the Buildable Acres MVA attribute.

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Preface

This study was conducted for Headquarters, U.S. Army Corps of Engineers (HQUSACE) under project 622720A896, "Environmental Quality Guidance," Work Package "Integrated Climate Assessment for Army Enterprise Planning," Work item L4F5G1, "Climate Change Impacts on Water and Energy for Army Installations." The technical monitor was Sarah Harrop, Headquarters, Department of the Army (HQDA).

The work was performed by the Energy Branch (CF-E) and Materials Branch (CF-M) of the Facilities Division (CF), U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). The CERL Principal Investigators were James Miller and Laura Curvey. At the time of publication, Andrew Nelson was Chief, CEERD-CF-E, Vicki Van Blaricum was Chief, CEERD-CF-M; and Michelle J. Hanson was Acting Chief, CEERD-CF. At the time of publication, Alan Anderson, CEERD-CV-T, was the Technical Director for Military Ranges and Lands, CEERD-CV-T. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

COL Jeffrey R. Eckstein was Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

1 Introduction

1.1 Background

Over the years, the needs of the U.S. Department of Defense (DoD) change, often resulting in an excess of facilities and installations that are no longer wanted or needed. Until the 1960s, DoD enjoyed wide latitude in disposing of unneeded facilities. This relative freedom ended in the 1970s when base closures were largely halted. During the 1980s under the Reagan Administration, the institution of "BRAC 88" temporarily reinitiated the Base Realignment and Closure (BRAC) process to overcome the political hurdles associated with BRAC impacts on various constituencies. The '88 DoD BRAC Commission reported to the Secretary of Defense, who forwarded the recommendation package to the President for approval/disapproval in its entirety. On presidential approval, the package was submitted to Congress for their approval/disapproval in its entirety.

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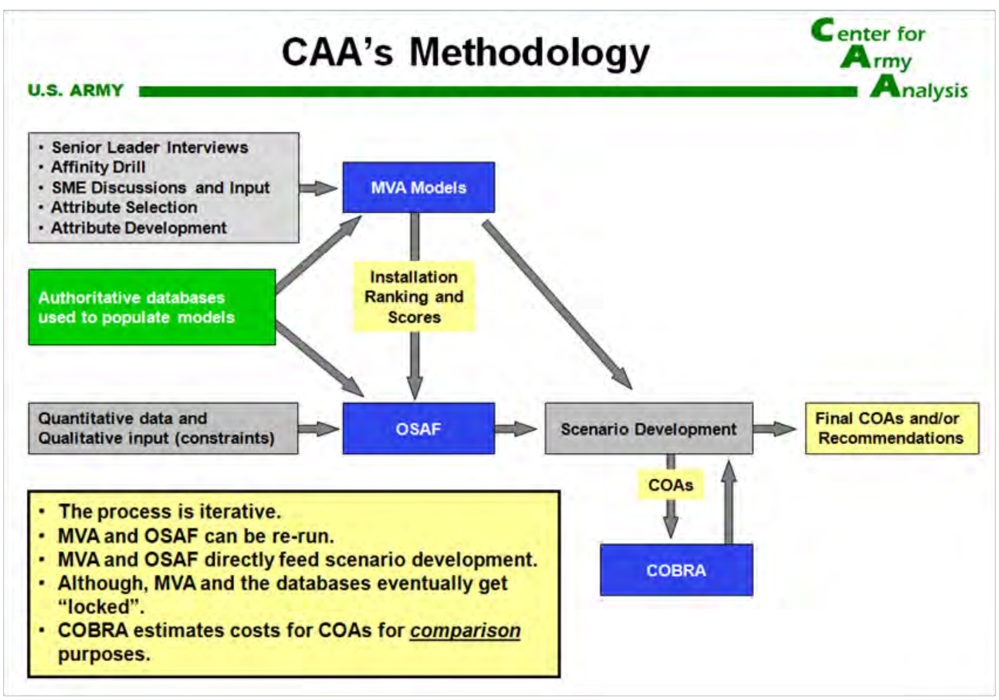
1.1.1 Current Optimal Stationing of Army Forces/Military Value Analysis (OSAF/MVA) process

Based on its experiences in a series of BRAC actions from 1988 to 2005 and other Army stationing activities, CAA developed an analytical process to optimize its stationing decisions based on costs and military value. CAA is constantly updating its process and running stationing models. Currently, CAA's process (Figure 1-1) is composed of four subprocesses:

1. MVA modeling
2. Evaluation of the Optimal Stationing of Army Forces (OSAF)
3. Evaluation of the COBRA
4. Formulation of final Courses of Action (COAs) and/or recommendations.

This iterative process builds on MVA models that are based on a set of attributes that define the Military Value of Installations according to Criteria 1 to 4. The MVA models result in installation rankings and scores that provide input to the OSAF model. OSAF and MVA outputs are combined to produce scenarios and COAs, which are then input to the COBRA tool. Ultimately, this process yields final COAs and recommendations.

Figure 1-1. Current CAA stationing decision analysis process.

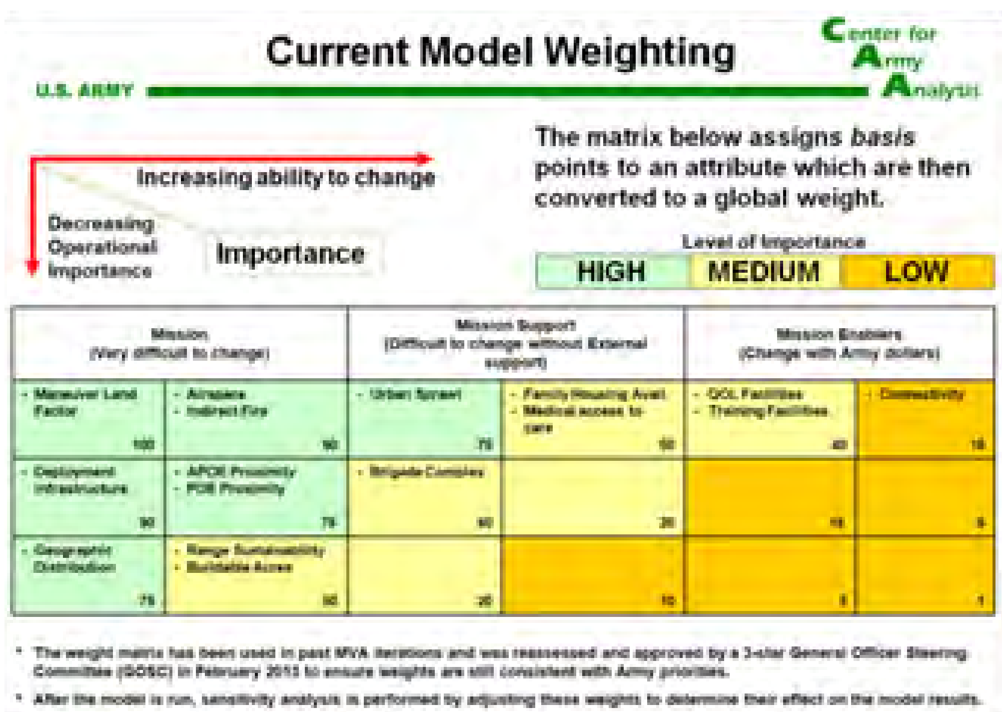


1.1.1.1 MVA modeling

MVA is a process of determining the Military Value of Installations based on a set number of attributes—quantifiable characteristics used in the MVA that relate to DoD selection criteria. Attributes are measures of various aspects of an installation's military value. Within the MVA, the attributes are weighted based on their operational importance and ease of change relative to each other. Each attribute has a specific weight, which is expressed by a value within the range of 0-10.

For example, recent stationing actions have considered such attributes as maneuver land availability, housing, and water quantity. The maneuver land attribute is considered to be of high operational importance, and one that is difficult to change since additional maneuver land is not easily acquired. Consequently, the maneuver land attribute is weighted more heavily than an attribute such as quality of life facilities, which is more easily changed since it can be improved by investment. Installations receive a value for each attribute based on collected data. Individual attribute scores are then weighted and summed to produce the installations' overall military value scores (GAO 2013). Figure 1-2 shows the weights assigned to attributes in recent small-scale CAA stationing efforts.

Figure 1-2. Current CAA MVA model weighting matrix (as of February 2013).



1.1.1.2 Evaluation of OSAF

The OSAF model was developed to determine the optimized stationing of Army Forces. Unlike the MVA model, which focuses on the value of installations, the OSAF deals with specific constraints that will affect the growth of installations. Working as an optimization model, OSAF seeks to maximize the NPV while still meeting Army requirements.

1.1.1.3 Evaluation of COBRA

Scenarios produced by OSAF are run through the COBRA model, which includes recurring and one-time costs, including environmental and waste management costs. These values are derived from Base Operation Support (BOS) costs, which are included in the Installation Status Report (ISR).

1.1.1.4 Formulation of COAs and/or recommendations

The MVA models result in installation rankings and scores that provide input to the OSAF model. OSAF and MVA outputs are combined to produce scenarios and COAs that are input to the COBRA tool. Ultimately, this process yields final COAs and recommendations.

1.1.2 Opportunities for process improvement

1.1.2.1 Consider a longer NPV horizon

The U.S. Army operates in an environment undergoing constant change. Budgets, political considerations, international threats, technological developments, and numerous other concerns require the Army to be in a constant state of planning and preparing for future needs. Inevitably, a major question faced by Army planners deals with optimizing the stationing of Army Forces for purposes of training, maintaining, and when necessary, deployment. OSAF is a very complex issue that rarely has an obvious solution. Decisions to station forces in one location versus another have a myriad of impacts, many of which can have effects for many decades into the future. As a result, careful analysis must identify and weigh all significant factors and impacts of Army stationing decisions.

BRAC 2005 required consideration of a 20-year NPV analysis. Since Army stationing decisions have very long term implications not only for the Army, but also for gaining and losing communities, and since the possible

effects of climate change may not be fully realized for decades, a 20-year NPV analysis may no longer be adequate. A longer NPV analysis (perhaps 40 to 50 years) may be more appropriate.

1.1.2.2 Consider climate change impacts

Climate change can be expected to affect Army installations in at least two critical areas: water and energy. Since stationing decisions have very long term implications and impacts, it is necessary to consider possible future effects of climate change on Army installations (see Appendix A). In the course of conducting a stationing analysis, it may become necessary to better distinguish between two or more installations that have very similar MVA scores based on Criteria 1 through 4. In making such distinctions, CAA must consider not only the abilities of existing and potential receiving communities to support forces, missions, and personnel (Criterion 7), but also the environmental impact of a stationing decision, including the impact of costs related to potential environmental restoration, waste management, and environmental compliance activities (Criterion 8).

1.1.2.3 Include environmental analysis in the stationing analysis process

While the current process is useful, CAA has expressed the belief that the process may benefit from further development and improvement. In particular, in its review of the 2005 BRAC, the Government Accountability Office (GAO) highlighted that DoD's environmental analysis was incomplete. Specifically, GAO said that DoD should have given better consideration to environmental restoration of bases undergoing closure or realignment (GAO 2005, p 45). To overcome such deficiencies in future analyses, existing attributes may need to consider additional metrics. If so, there is a need to identify those metrics, to identify and locate the data available to evaluate them, and to devise a method to calculate them. A broader concern is whether there is a need to consider additional relevant attributes not yet included in the current process. Again, if that is the case, then there is a need to identify those attributes, to identify and locate the data available to evaluate them, and to devise a method to calculate them.

Although its stationing decision analysis process has worked well in the past, CAA has expressed the desire to improve the process for use in future stationing analyses. Since climate change can be expected to have an impact on the Army's costs and ability to fulfill its missions, it is in the

Army's interest to include an environmental analysis in stationing decisions to enable the Army to better predict and respond to the effects of the changing climate. Army installation realignment may be affected by climate change, or it may further exacerbate problems resulting from climate change in a particular area. Stationing analyses that consider climate forecasting can recognize future uncertainties while also striving to best prepare for the consequences of climate change. The inclusion of climate factors in the stationing analysis process will enable a more complete modeling and cost analysis.

To assist CAA in its effort to improve the stationing analysis process, this work aimed to:

- gather and manage a new dataset for use in other efforts
- consider possible additional attributes for the MVA model
- develop environment-related constraints for the OSAF model
- assist in specific scenario-related development
- contribute to analysis of environmental impact (Criterion 8).

1.2 Objectives

The objective of this work was to assist CAA in evaluating the current Army stationing analysis process and in responding to the critiques on the process brought forward by the GAO by focusing on the possible ramifications from Global Climate Change (GCC) on the stationing decision analysis process, specifically with respect to Criteria 7 and 8.

1.3 Approach

The project team studied the CAA stationing analysis process to gain a working understanding of the existing system. Team members sought to increase the depth of environmental (and, in particular, climate change-related) analysis in the existing MVA attributes so that an improved environmental analysis could be used in general stationing. Where it appeared that climate change might affect existing MVA attributes, the team sought possible metrics to improve those attributes. The team then sought data sources that could be applied Army-wide. When such data were available, the team developed methods for calculation of those metrics.

This project team focused on attributes and metrics associated with climate change impacts on water and energy at Army installations and facilities. In parallel efforts, other project teams considered how climate change might impact installations' abilities to deploy forces and to conduct firing and maneuver training on Army training ranges.

The first step of this approach was to gain a familiarity with the CAA stationing decision analysis process. The next step was to consider the projected impacts of climate change and how they might be expected to affect Army installations. This included an investigation of existing MVA attributes that appeared to be subject to possible climate change effects. Also considered were any new MVA attributes that might merit further consideration and development. In considering any candidate MVA attributes, every attempt was made to keep the "SMART" approach in mind such that any proposed attributes should be:

- **Specific** – clear and focused to avoid misinterpretation; assumptions and definitions should be easily interpreted or explained.
- **Measurable** – can be quantified and compared to other data; should allow for meaningful statistical analysis (avoid binary "yes/no" measures – those become "screening" criteria).
- **Attainable** – achievable, reasonable, and credible under conditions expected.
- **Realistic** – fits into the models and is cost-effective.
- **Timely** – achievable within the time frame given.

After identifying relevant MVA attributes, metrics were then identified that could be used to quantitatively score installations against each other. Metrics imply the need for data, so existing data sources that could be used in calculating metrics were investigated. To be useful, data must be reliable, credible, maintainable, and commonly available for all Army installations.

For all metrics for which suitable data were available, methods for calculation of scores for each metric were developed and documented.

Subsequent chapters of this report briefly address proposed augmented MVA attributes, their associated metrics, available data and calculation methods. More detailed discussions are provided in the appendices.

1.4 Scope

Seven case study installations that span the continental United States and are located in a variety of climate zones were selected to provide means to test the impact of climate change on the U.S. Army (Table 1-1 and Figure 1-3). All methods used in this study are scalable and can be used to assess all Army installations located within the United States.

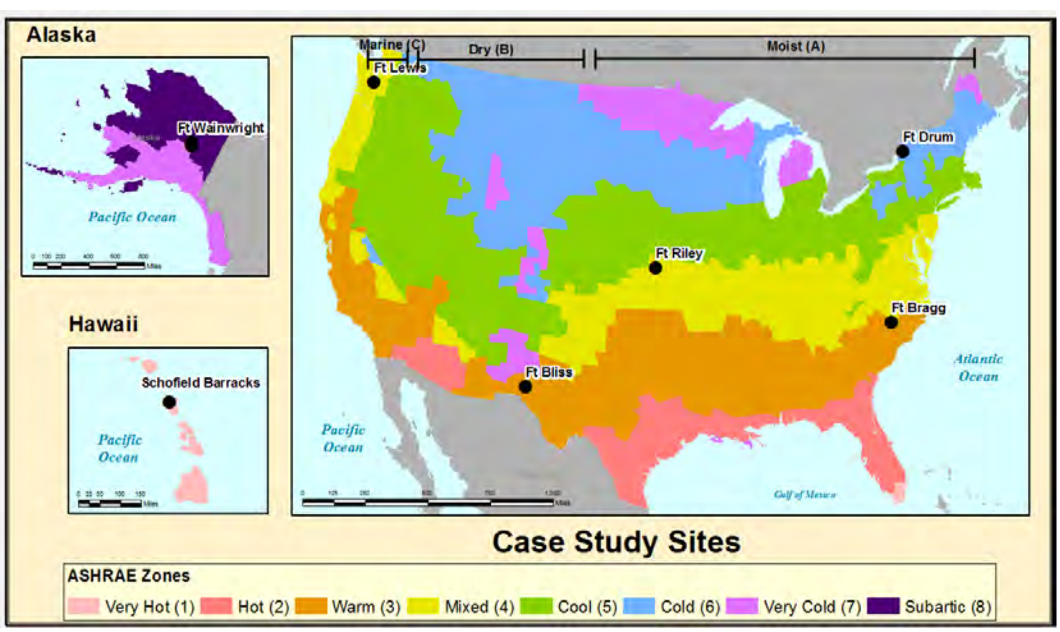
1.5 Mode of technology transfer

It is anticipated that the results of this work will provide a foundation for follow-on research in support of CAA Army stationing (restructuring and realignment) analyses.

Table 1-1. Summary of climate zone and installations

Installation	State	ASHRAE Climate Zone
Fort Lewis	WA	Mixed-Marine
Fort Bliss	TX	Warm-Dry
Fort Riley	KS	Mixed-Moist
Fort Drum	NY	Cold-Moist
Fort Bragg	NC	Warm-Moist
Fort Wainwright	AK	Subarctic
Schofield Barracks	HI	Very Hot

Figure 1-3. Spatial distribution of the case study sites in relation to their climate zones.



2 Climate Change Impacts – General

Climate change is a real phenomenon that (per the 2014 National Climate Assessment) already impacts the United States and that can be expected to impact Army installations and operations in a variety of ways. Although climate change is not always obvious, ongoing effects in the coming decades are expected to be significant, especially as related to global temperature changes, the frequency and intensity of storms, increases in numbers and intensities of droughts and floods, and changes in supply and costs of associated water and energy resources.

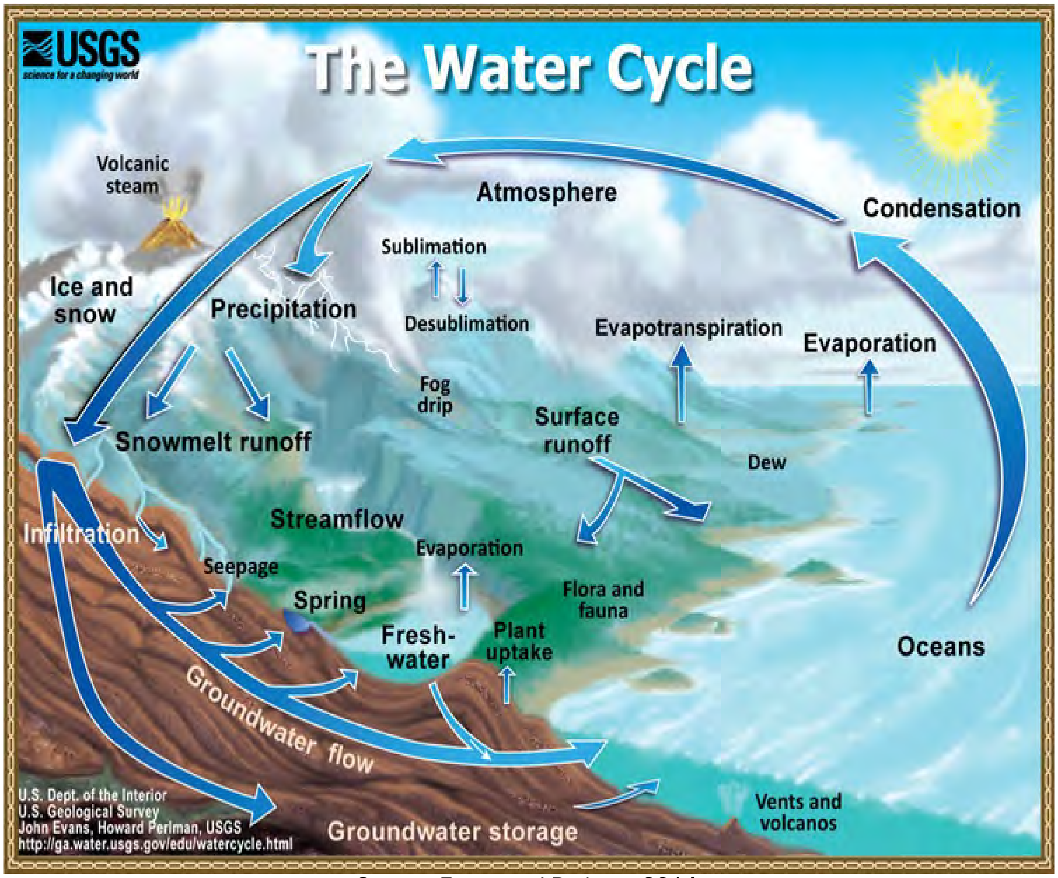
2.1 Impact of climate change on water

2.1.1 Changed water cycle

The Earth's water is always in movement, cycling from the atmosphere to land and the oceans (via precipitation and runoff) and back to the atmosphere. This hydrologic cycle (Figure 2-1) is a dynamic and naturally varying process that is necessary for all life to exist. While societies and ecosystems are accustomed to this variability, climate change is affecting the hydrologic cycle in new ways at various times and geographic scales (Geogakakos et al. 2014). While the mass of water on Earth remains constant over time, the portioning of the water into ice reservoirs, fresh water, salt water, and atmospheric water is shifting. These shifts may result in increased drought, warmer temperatures, and storms of greater intensity.

The warming of the planet is expected to result in significant changes in the water cycle since the movement of water in the oceans and the atmosphere is one of the primary mechanisms for the redistribution of heat around the world (Karl, Melillo, and Peterson 2009). Warm air can hold more moisture than cold air. For every 1 °F temperature increase, the capacity of the atmosphere to hold water increases by about 4% (Braconnot et al. 2007). As global temperatures increase, the atmosphere will hold additional moisture from evaporation of water from both land and the sea.

Figure 2-1. The hydrologic cycle is the cycle of water moving from the Earth to atmosphere and back. The hydrologic cycle is naturally in flux, but climate change is altering the hydrologic cycle.



Source: Evans and Perlman 2014

2.1.2 Changed precipitation patterns

The individual components of the water cycle are linked to each other so that changes in one part of the cycle can affect other portions of the cycle. Concurrent changes in atmospheric circulation are moving storm tracks northward, reducing precipitation in the arid Southwest and intensifying the drought in that area, while increasing precipitation in the Northeast, Midwest, and Alaska (Karl, Melillo, and Peterson 2009).

Increased evaporation of water vapor into the atmosphere will ultimately result in increased global precipitation. This increased precipitation will not be uniformly distributed so that some locations will see significant total annual precipitation increases while other locations will experience decreased annual precipitation totals. Another effect is that individual precipitation events may be much larger than normal since high levels of

water vapor in the atmosphere and warmer temperatures feed the intensity of storm events (Walsh et al. 2014).

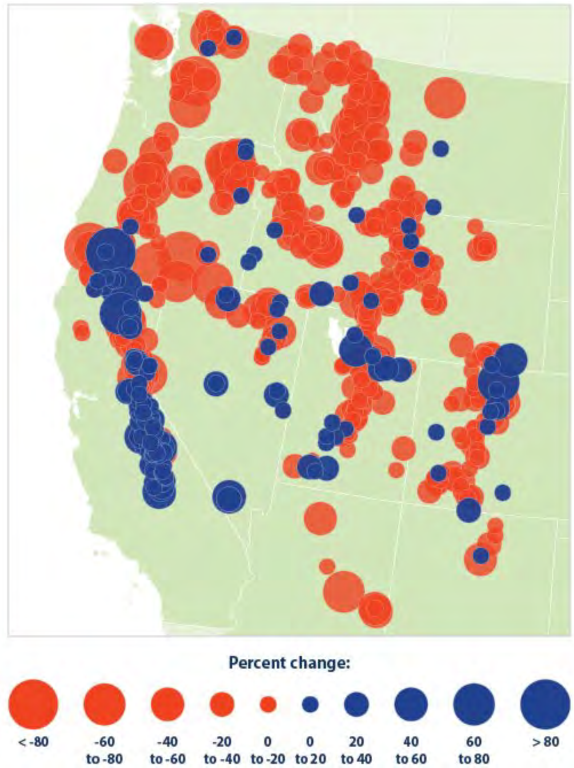
Models predict that the northern United States will have additional precipitation (particularly in the winter and spring) while the southern United States will have reduced precipitation, particularly in the spring. While total precipitation amounts may fall or remain constant in the southern United States, the amount of rain falling in single storm events is likely to increase in most regions.

2.1.3 Loss of snowpack

Furthermore, the proportion of precipitation falling as rain versus snow has increased. Snowpack, a vital water source and cooling agent, is shrinking. Analyses conducted by the U.S. Environmental Protection Agency (USEPA) found a decline in snowpack at 75% of their monitoring sites in the western United States with an average decline of about 14% (USEPA 2014a). As Figure 2-2 shows, the decline has not been generally consistent. There has been a noted increase in snowpack in the Sierra Nevada Mountain Range. The declines in the snowpack are temporarily increasing water supplies and increasing precipitation, resulting in some flooding. In the long term, these regions will have less water, as an increase in air temperature of 4.3 °F could reduce stream flows by 12% or more for much of the western United States (Berghuijs, Woods, and Hrachowitz 2014).

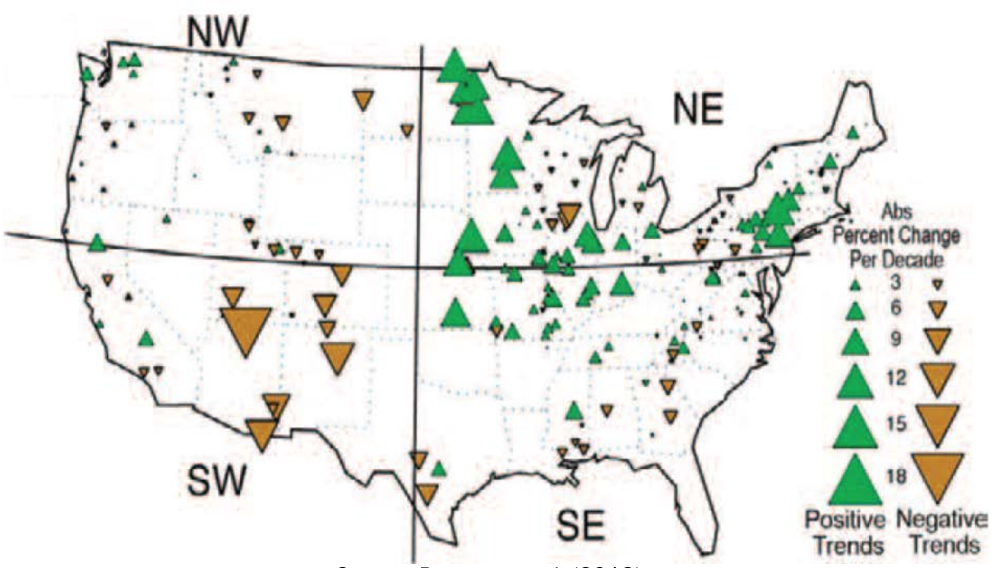
In western states that depend on spring thaws, increased snowpack melts from higher temperatures will temporarily increase flooding and river flow rates, and improve water quality, but will eventually cause water supplies to diminish as those snowpacks are no longer restored during the warmer winter months. Current weather patterns manifest these regional shifts. Figure 2-3 shows that shifts in flood frequency have not been evenly distributed throughout the United States. The Northeast has had increases in flooding while much of the Southwest has experienced reductions in flooding (Peterson et al. 2013).

Figure 2-2. Trends in April snowpack from 1955-2013 in the western United States demonstrate that, in general, there has been a decline in the snowpack size.



Source: USEPA (2014a).

Figure 2-3. Regional trends in century-long flooding.



Source: Peterson et al. (2013).

2.1.4 Localized water shortages

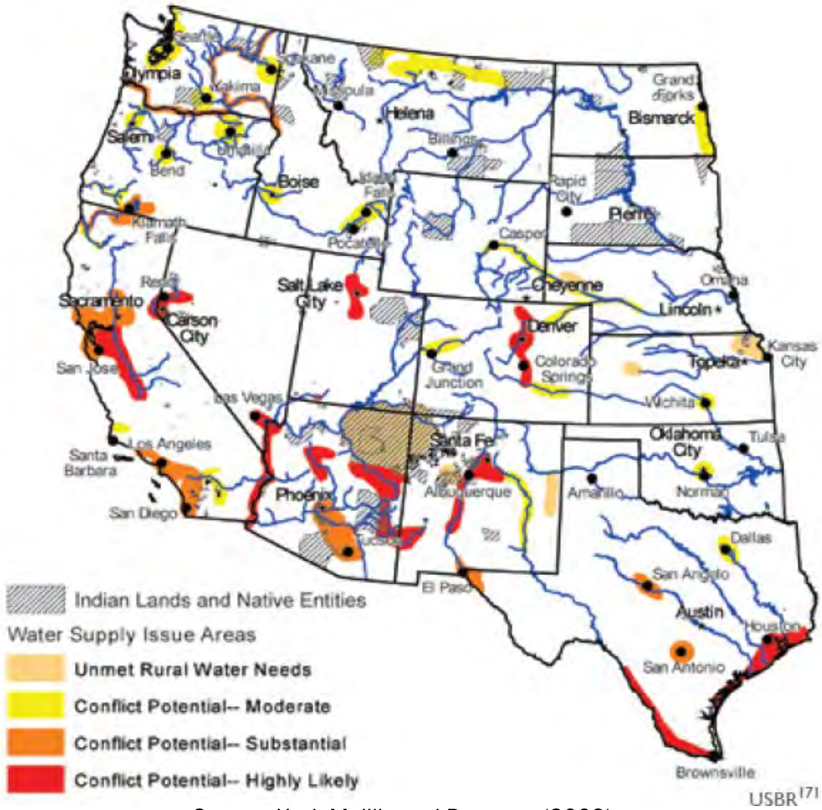
The implications of GCC on water resources in the United States will vary between regions. Some areas will experience minor divergences from the norm while others will undergo increases in extremes (Peterson et al. 2013). Areas such as the southwestern United States are expected to continue to experience reduced precipitation levels and decreased water flow in rivers and streams due to lower annual precipitation and reduced snowmelt. These areas will have to cope with increasing water scarcity despite a rising population. This combination of circumstances will accelerate increases in the cost of water, place limitations on irrigation, and degrade overall water quality.

In the Southwest, the fastest growing region in the United States, there is a clash between population growth and reduced rainfall and water supplies. Figure 2-4 shows seven metropolitan areas in which conflict over water supplies is likely to occur by 2025: Denver, CO; Houston, TX; Santa Fe, NM, Salt Lake City, UT; Carson City and Los Vegas, NV; and San Francisco, CA (Melillo, Richmond, and Yohe 2014). This analysis, which excludes climate change-related water pressures, demonstrates that current water demands are higher than supply. Additional water pressures associated with climate change can only exacerbate these water conflicts (Karl, Melillo, and Peterson 2009).

These conflicts have already begun. California state water officials, in response to the multi-year drought that has caused a rapid decline in the smelt population and coupled with the demands of the urban California population, have ordered the water dependent farmers of the San Joaquin Valley in California to reduce their water intake for the good of the roughly two-thirds of Californians who are downstream users of the Sacramento-San Joaquin River Delta (Hackman 2015). Figure 2-5 shows a popular response to the restriction.

In 2014, Texas state regulators forced hundreds of farmers to stop pumping water from the Brazos River because a petrochemical plant downstream with senior rights to the water demanded more water from upstream. However, in the name of safety and public health, cities and power plants along the river were exempted from this requirement (Wines 2014).

Figure 2-4. This map demonstrates regions in the Western United States where water supply conflicts are likely to occur by 2025. This analysis does not factor in climate change



Source: Karl, Melillo and Peterson (2009).

Figure 2-5. Sign in Central California protesting the reductions in water for farming.

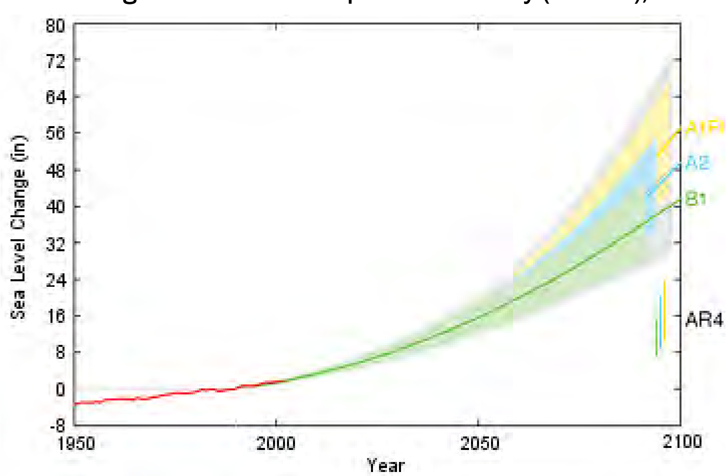
Source: Lynn Friedman/Flickr.

The effects of climate change and the public's desire to support current quality of life levels are pressuring water supplies throughout the United States even in relatively water rich locations. For example, the over-pumping of New Jersey's Potomac-Raritan-Magothy aquifer system has dropped its water levels by more than 100 ft. This over-pumping of the aquifer, combined with rising sea levels has resulted in increasing salt water intrusion into the freshwater supply. As freshwater is less dense than salinated water, the aquifer is still able to produce potable water. Yet the farther the water level is drawn down, the more that saltwater is able to intrude and contaminate the aquifer.

2.1.5 Sea level rise

Increasing temperatures contribute to shifting of hydrologic patterns through accelerated melting of Arctic glaciers, which in turn increases the rate of global sea level rise (SLR), which is well documented and will have tremendous implications on the mission of the U.S. Army. Because of SLR, some installations may have reduced access to training lands while in other areas, key infrastructure may be damaged or destroyed. Over the past century, the Global Mean Sea Level (GMSL) rose at an average rate of 1.7 mm a year. From 1993-2010, sea levels have risen by an average rate of 3.2 mm per year (Stocker et al. 2014). Thermal expansion, the melting of glaciers and polar ice-caps, and ice loss in Greenland and Antarctica are all causes for the rise in GMSL. Figure 2-6 shows SLR projections from 1990 to 2100 based on three emissions scenarios.

Figure 2-6. Projected SLR from 1990 to 2100, based on three different emissions scenarios, and observed annual global SLR over the past half century (red line), relative to 1990.



Source: NRC (2010).

2.2 Impact of climate change on energy

The effects of climate change on energy and water are closely related. Water plays an integral role in the production of electricity, and the energy infrastructure is vulnerable to conditions characterized by too much or too little water—those conditions caused by the warming climate. GCC projections touch every sector of energy, from production and generation, to transportation and distribution, to demand. The main GCC factors that create vulnerability in the energy sector are: (1) increasing air and water temperatures, (2) decreasing water availability across regions and seasons and (3) increasing intensity and frequency of storm events, flooding, and SLR (USDOE 2013).

2.2.1 Increasing air and water temperatures

Air and water temperatures affect many energy sectors such as oil and gas production, thermoelectric power generation, biofuel production, solar energy, the electric grid, and energy demand:

- Oil and gas production would experience changed infrastructure requirements due to thawing permafrost in the Arctic with longer ice-free Arctic seasons.
- Plants using coal, natural gas, nuclear, and geothermal means to generate electrical energy also require significant amounts of water in their cooling processes. Increasing ambient air and water temperatures increases the likelihood that effluent water temperatures will be higher than allowable standards, which can damage the local ecology and increase the risk of facility shutdowns (USDOE 2013).
- Biofuels and bio-energy would require higher irrigation demand and would be more susceptible to crop damage from extreme heat events and droughts.
- Crystalline silicon photovoltaic (PV) cells are sensitive to increasing temperatures and are more susceptible to heat-related efficiency losses (USDOE 2013).
- Approximately 7% of power is lost in transmission and distribution (EIA 2007). Assuming that temperatures rise as expected, a California study predicts that transmission losses will increase while the capacity of transmission lines will decrease (Sathaye 2013).
- As air temperature increases, the demand for energy for cooling will increase in warmer climates.

2.2.2 Decreased water availability

Decreased water availability would affect all stages of oil and gas production from drilling to production and refining. Decreased water availability would also likely affect transportation by reducing water levels of navigable rivers, which would disrupt barge transport of petroleum products and coal. Decreased water availability would reduce the efficiency and capacity of hydropower plants and any type of power-generating plants that require cooling. The associated increased chances of drought would also diminish the production of biofuels.

2.2.3 Increasing intensity and frequency of storm events, flooding, and SLR

In addition to raising the global sea level, increased temperatures and melting of polar ice-caps will result in increasing intensity and frequency of extreme storm events and floods. This trend is likely to continue as air temperatures increase, thereby melting more of the polar ice-caps. The greater frequency of more extreme events increases the probability of damage to all types of infrastructure, including the highly vulnerable energy sector. Extreme weather and flooding have damaged electrical grids, oil platforms, rail and barge transportation systems, and have inundated commodity fields for biofuels. SLR has the potential to impact coastal power-generating facilities and river fuel transport systems.

3 Climate Change Impacts on the Army

3.1 Army energy and water strategies

3.1.1 Army energy strategy

For DoD, energy security means assuring access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet mission-essential requirements. DoD's Strategic Energy Security Goals (ESGs) are to:

- Reduce energy consumption
- Increase energy efficiency
- Increase renewable/alternative energy
- Assure access to energy supply
- Mitigate harmful environmental impacts.

Three key objectives defined to ensure energy security include:

1. Developing more "energy-efficient weapons systems, platforms, equipment and facilities"; investing in cost-effective energy sources; and integrating energy analysis into decision making and business processes.
2. Promoting energy security of non-DoD capabilities, equipment and infrastructure that indirectly support defense missions and assets.
3. Advancing future missions and capability through technological innovation.

3.1.2 Army water strategy

The Army generally defines water resources in terms of their value for consumption—their availability to be consumed, their availability to support additional consumers, and their costs. For example, the *Water Quantity* MVA attribute defines the amount of water that an installation can consume. This enterprise-wide strategy is underscored in recent Army directives, such as the Army Energy Security Implementation Strategy (AESIS) Plan and Executive Order (EO) 13514, which requires the following water use reductions relative to a 2007 baseline:

- potable water (26% by the end of FY20)
- industrial, landscaping, and agricultural water (20% by the end of FY20) (Army Energy and Water Management Program 2014).

Yet the effects of water and water stress go beyond the consumptive uses of the resource. Reductions in a water supply will have implications on other sectors—ranging from electricity production, to wetland amphibians, to reduced crop production. The Army often overlooks the destructive consequences of too much or too little water, such as SLR, drought, and increased flooding. The main Army water management goal, which deals with the destructive nature of water, is the sustainability goal (EPAct 05, Sec. 109).

Bifurcating the "natural" and consumptive uses of water in Army analysis leads to an incomplete understanding of water stress as it affects Army installations. This narrow interpretation of water ignores the other effects that water may have on an installation, while recognizing that potable water is crucial for survival.

These recommendations and analyses are based on a holistic understanding of the effect that water has on the MV of an installation by pairing the current view of consumption with natural forces. This water analysis explores the nexus of water consumption and natural forces, shedding light on the relationship between these two considerations. For example, this work demonstrates how climate change may reduce water supplies in some portions of the United States (a natural force) and how that may reduce the amount of water available for Army use (consumption). Analysis conducted by the RAND Corporation for the U.S. Army found that water scarcity due to climate change will be one of the key challenges for the United States Army in coming years (Lachman et al. 2013).

3.2 Reduced ability to respond

Climate change will affect the capacity of the U.S. Army to respond to events in fulfillment of its mission. The 2014 Quadrennial Defense Review stated that, because of climate change, the frequency, scale, and complexity of future military missions may be affected (DoD 2014). Rather than building a military to respond to the effects of climate change, the Center for Naval Analyses (CNA) Corporation's Military Advisory Board has advised the U.S. military to be ready to respond to the variety of challenges that will come. The reduction in the Army's ability to respond to its mission as a result of climate change can be characterized in three ways: reduced capacity, reduced military training, and reduced infrastructure (CNA Military Advisory Board 2014).

Destruction of the infrastructure will affect an installation's readiness to deploy. The CNA Military Advisory Board has stated that it is just as important to look at the infrastructure in the communities surrounding installations as the installations themselves. The readiness risk is higher now than at any previous historical point as there is less redundancy in personnel. The military has been engineered to develop more combat capacity with fewer units, so that consequently "the degradation of a given base today has much more impact to overall military capability than in the past." (CNA Military Advisory Board 2014, 24). Installations will clearly be affected if compromises to the infrastructure in the communities surrounding the installation hinder Soldiers and civilians from getting to work. It will not be sufficient to harden Army installations if, for example, roads leading to the installation are impassable due to high waters or the region experiences a power outage due to a water shortage at a power plant's cooling facilities.

Increased storm intensities and SLR will destroy crucial infrastructure that military installations require. Rising seas and storm surges can be large enough to damage bridges, such as the Mantoloking Bridge (Figure 3-1), which was washed out during Hurricane Sandy (2012). The effects of the storm demonstrate the vulnerability of infrastructure to both SLR and storm surges. Currently more than 60,000 miles of coastal roads are occasionally exposed to coastal waves and surges (Douglass and Krolak 2008). SLR and storms of greater intensity will increase the number of roads and severity of roads inundated with seawater. The risk of roads being washed out after a storm surge event reduces the capacity of service members to rapidly deploy.

The coasts of the United States are major economic hubs that serve as crucial points in the supply chain. Six of the top 10 freight gateways in the United States (by value of shipment) will be placed at risk by SLR. The Gulf Coast, the vulnerability of which was demonstrated in the hurricanes of 2005, has seven of the 10 largest domestic ports as measured by tons of traffic (National Research Council et al. 2008). Destruction of this infrastructure could affect the rapid deployability of units, as regional infrastructure that they depend on may not be usable.

Figure 3-1. An image of the washed out Mantoloking Bridge in New Jersey after Hurricane Sandy in 2012.

Source: Nesius (2012)

Additionally, destruction of ports may affect shipments of food and other goods to installations and their surrounding regions. Rising sea levels can restrict boats from passing under bridges, affecting commerce, travel, and supply lines. For example, in Fishing Creek, MD, SLR has caused rising tides such that many fishing boats and some cargo boats can no longer clear the Maryland Route 261 bridge to get to the Chesapeake Bay (Hille 2013). In California, over 1,900 miles of roads are currently at risk of a 100-year storm event. This number is expected to double to 3,500 miles if global SLR exceeds 1.4 meters.

3.3 Reduced capacity

The military's overall mission capacity is likely to be reduced because of climate change. As storm events increase in intensity, active Army, Army Reserve, and Army National Guard units could be called on to respond to these storm events. The CNA Corporation's Military Advisory Board expects that the use of active forces in Defense Support of Civil Authorities (DSCA) will increase, stressing the Guard, Reserve, and the U.S. Army Corps of Engineers (USACE). Further complicating the capacity of the Army is the implementation of the "total force" concept, in which some capabilities exist only in the National Guard, Army Reserves, or USACE.

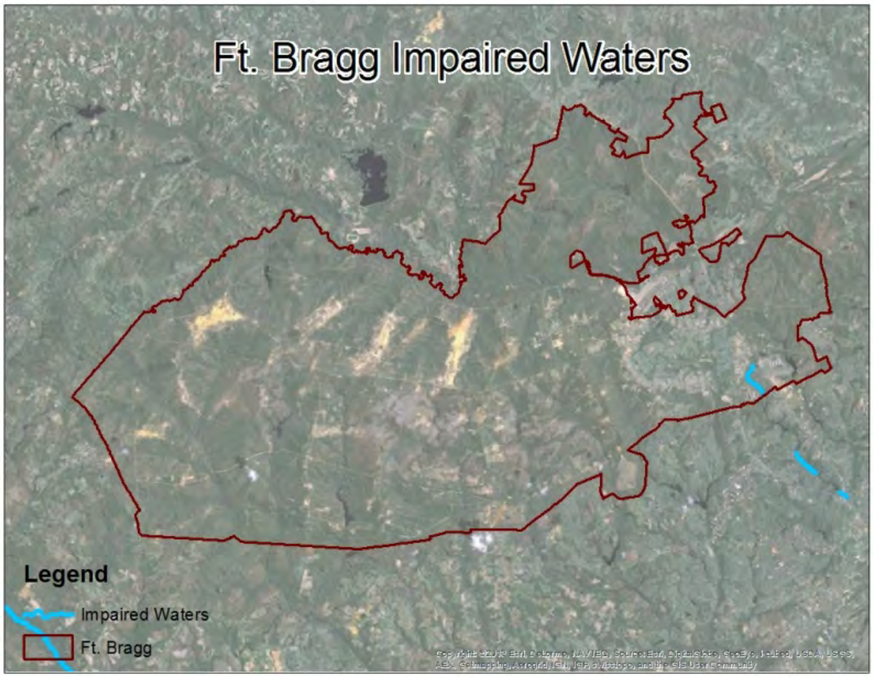
However, these components are being deployed with increasing frequency to respond to natural disasters such as wildfires, flooding, snow storms, and or natural disasters in which troops are required to provide and distribute water. The CNA Military Advisory Board (2014, p 23) writes that:

> We believe that the increased frequency, duration, and magnitude of these extreme weather events will stress these organizations' capacities and increase the degree to which active forces will be called on in DSCA missions.

A number of climate change effects (increasing air and water temperatures, storms of greater intensity, and droughts) can decrease water quality (Geogakakos et al. 2014). More specifically, increased sediment, nitrogen, and pollutant loads will reduce the quality of water resources. In this new climate regime, Army installations may be forced to curtail activities to prevent their water supplies from exceeding the threshold of contaminants in water legally defined by the CWA, which ensures clean water by requiring that contaminants present in water be below the Total Maximum Daily Load (TMDL), a contamination threshold set by states, territories, or authorized tribes. TMDL is a calculation of the amount of pollutant that a body of water can receive and still be potable (USEPA 2014). When the level of contaminants is above the TMDL, waterways are classified as "impaired water" and are subject to strict pollution and reporting standards.

Army installations are not exempt from TMDL restrictions. While operational shifts to reduce TMDL of contaminants may be minor and temporary, these shifts could be required for an indefinite period. Installations may have to change infrastructure, water treatment technologies, or use of facilities to reduce their runoff TMDL (USEPA Office of Water 2008). One result of having water surrounding an installation classified as impaired is a reduction in training or other activities that may pollute water. For example, in 2011, a 1.2-mile segment of the Little Cross Creek on Fort Bragg was measured above the TMDL level and was classified as "impaired water" (Figure 3-2). As a result of this classification, Fort Bragg has been required to perform increased monitoring and reporting. Fort Bragg's permit application (No. NCS000331 2011) to discharge storm water into the Little Cross Creek lists the following required actions: reporting use of Best Management Practices (BMPs), annual reporting on the effectiveness of BMPs, development of a monitoring plan for each pollutant of concern, and the development of an implementation plan.

Figure 3-2. Impaired waterway at Fort Bragg, NC.



3.4 Reduced availability of training lands

Extreme weather events such as droughts, floods, snow, and ice storms have significant impacts on military training operations through increased risks to life and safety, injury, and reduction in mission performance. In wartime operations, Commanders are forced to take large risks to execute their mission in extreme weather events. However, in peacetime training, Commanders are expected to refrain from putting lives at risk under extreme weather conditions. The expected change in weather patterns from climate change will reduce the number of training days. If conditions are too dry, the risk of wildfires increases, reducing training capacity. Under such dry conditions, the use of live-fire, high explosive rounds, and tracer rounds is suspended (or allowed only with extraordinarily precautionary measures) when the risk of wildfires is high. Furthermore, heavy rainfall and low visibility increases risks and limits training where visual feedback is required (Hayden et al. 2013, CNA Military Advisory Board 2014).

Texas experienced historic droughts in 2011. Under these drought conditions, three fires started at Fort Hood that summer during live-fire training. During the 2011 season, over 19,000 acres of training land (over 8% of

installation land) were consumed in wildfires (Vanover 2014). As a response to the fire risk, training with live rounds and tracer rounds was suspended. The ban on this training extended for so long that Commanders ultimately used helicopters to drench training lands and prepositioned fire trucks to enable Soldiers to train with live-fire (CNA Military Advisory Board 2014).

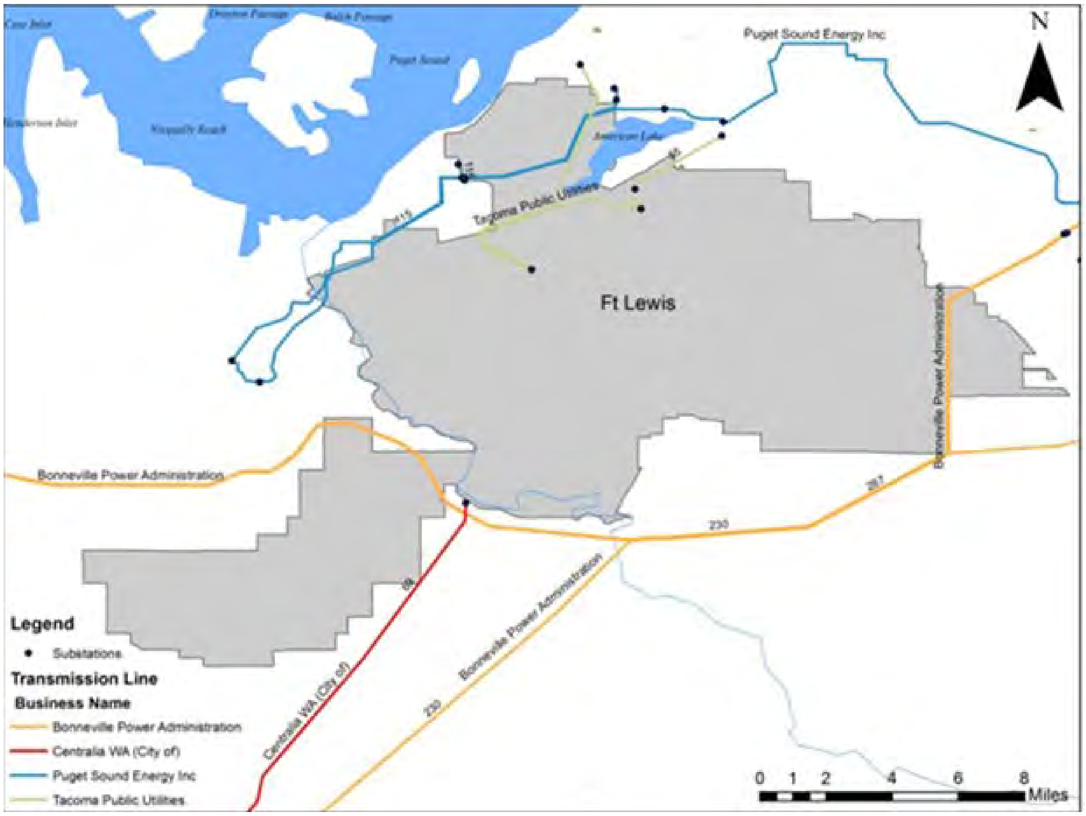
Furthermore, SLR will inundate low-lying buildings and reduce available training land. The 2014 Quadrennial Defense Review recognized this challenge in its statement that "the Department's operational readiness hinges on unimpeded access to land, air, and sea training and test space" (DoD 2014). Rising sea levels and large storms increase the likelihood of inland flooding from storm surges. Analysis of 55 sites on the Atlantic, Pacific, and Gulf coasts of the contiguous United States conducted by Climate Central, a nonprofit organization focused on researching and reporting the science and impacts of climate change, found that 66% of these locations are expected to have a 100-year flood event within the next 18 years. Additionally, they determined that many of these floods would be caused by storm surges (Strauss, Tebaldi, and Ziemlinski 2012). For the Army, coastal training lands may become unavailable for training maneuvers with higher tides and lands saturated with water.

3.5 Reduced energy security

Overall, the effects of climate change on the existing energy infrastructure may be modest, but local and industry specific impacts could be large, especially in sensitive areas prone to warming (Alaska) or weather disruptions (coastal regions) (Bull et al. 2007). Electric grid vulnerability can increase the occurrence of power outages. Army activities, including basic day-to-day functions, are dependent on this interconnected electrical network.

For example, reductions in precipitation (increasing drought conditions) especially in the Pacific Northwest of the United States, have already affected the Bonneville Power Administration (BPA). BPA markets electric power from the Bonneville Dam located on the Columbia River to Joint Base Lewis-McChord (JBLM) through a utility services contract for Federal sites (Steucke 2012). Figure 3-3 shows four transmission lines serving the installation.

Figure 3-3. Transmission lines owned by four electric utility companies that service JBLM.



BPA's vulnerabilities to climate change include a reduction in the surface water supply due to decreased snowpack in the winter and earlier snow melt in the spring (Melillo et al. 2014). The resulting lower river flows will directly affect the energy supply to JBLM because the BPA and City of Centralia, WA, use hydropower to generate electricity. Since BPA is a major electric provider to the region (30% of electric power used in the Northwest [BPA 2013]), predicted climate changes that affect the timing of snowmelt streamflows will increase the competition for water resources and can limit the availability of electricity to JBLM (Melillo, Richmond, and Yohe 2014).

Damaged infrastructure due to SLR, storm surge, and flooding

With a changing climate, installations are at risk of flooding from SLR, storm surge, and inland storm events. SLR and storm surge will have a minimal impact on the direct mission of the U.S. Army, as only 10 installations are located on the coast. However, these 10 coastal installations face the challenge of land loss due to SLR. This analysis concludes that by 2070, an additional 2,703 acres of Army installations are expected to be

inundated with sea water. While this accounts for just over 0.58% of land of coastal installations, the effects range from 0.1 acres at Fort Hamilton to over 1,400 acres at Joint Base Langley-Eustis.

The infrastructure that installations rely on is also at risk of SLR and inland flooding resulting from climate change. Since the sites in the Defense Critical Infrastructure Program (DCIP) are classified, this analysis centered on community infrastructure at risk of SLR and flooding. The tools and methods developed for analyzing community infrastructure can be applied to sites cataloged in DCIP. The community infrastructure analyzed was that located within 40 miles of an installation that was at risk of flooding during the specific horizon or storm event. Temporary disruptions to the services provided by these facilities because of changing climate may affect the physiological well-being of service members. For example, if a number of schools in the community surrounding an installation were destroyed in a storm event, this would not directly affect the capacity of the installation, but it would affect service members and supporting civilians with children who attend those schools who would be unable to accomplish their work to full capacity.

In addition to the 10 coastal installations, an additional 18 are located within 40 miles of the coast. These installations will not lose land to SLR, but will be affected by the loss of infrastructure in the surrounding region.

3.5.1 Limitations and assumptions of SLR and storm surge analysis

3.5.1.1 Storm surge threshold

For calculating storm surge, the selected threshold was the likelihood that in the decade examined (either 2050 or 2070), there is at least a 51% chance that water will exceed the elevation threshold. This threshold was selected for two reasons. First, a 51% threshold demonstrates that there is a higher likelihood of water reaching that point in the decade than not, thereby demonstrating a real risk. Secondly, the 50% threshold is used on the Climate Central website and in its data downloads. For each coastal city or county, users are able to download an Excel spreadsheet that provides the decade by which there is a ⅙ and ½ chance of flooding to elevations of 1 to 10 ft above local mean high tide. By using their existing scale, it was possible to fit into the existing common uses of the data.

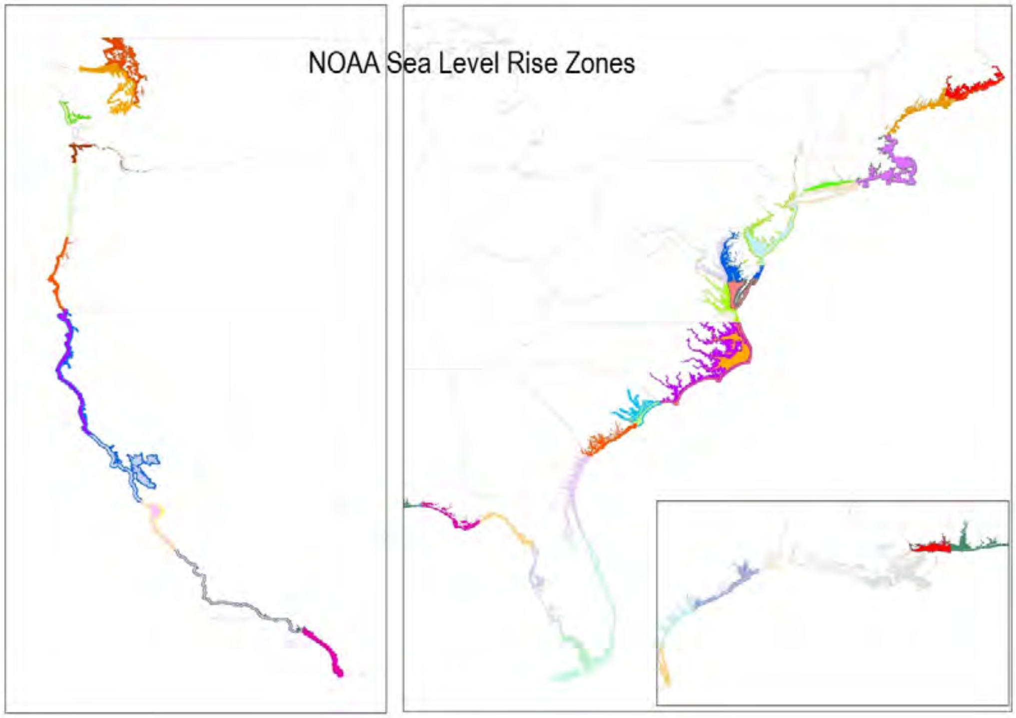
3.5.1.2 Rounding of SLR

The National Oceanic and Atmospheric Administration (NOAA) data provide SLR impacts in 1-ft intervals, rather than on specific time lines. As a result, the projected SLR (determined from the NOAA tidal gauges) was rounded to the nearest foot. When analyzing military installations within 40 miles of a coast for SLR in 2050, the majority of the installations (57%) had their estimates rounded down. As a result, these estimations reflect a level of conservatism. One challenge of this rounding is that the changes in the landscape resulting from climate change are not fully illustrated. For example, Fort AP Hill outside of Washington DC is expected to have 0.97 ft of SLR in 2050 and 1.44 ft in 2070. When rounding is applied, it appears as if the installation has no changes in its SLR vulnerability.

3.5.1.3 Extent of storm surge

To determine the vulnerability of energy infrastructure to climate change, a national dataset was developed. One limitation of this dataset is the scale of the underlying SLR data, which was provided at National Weather Service Weather Forecast Office (WFO) regions broken out at the state level. In Figure 3-4, some states such as Georgia had their entire coast depicted as a single zone, whereas Florida's coast was broken into six separate parts. As these layers represent the expectations for how that amount of SLR would affect the region and it is not on a specific time scale, places in the same region may experience the projected amount of SLR at different times. When rounding is applied, the extent of SLR for the years 2050 and 2070 is consistent across data zones with the exception of Massachusetts. A larger problem comes when calculating storm surge. For example, Fort Meade and Aberdeen Proving Ground both have a greater than 50% chance of having a 5-ft storm surge by 2050. Fort Belvoir, which is in the same region, may experience an 8-ft surge. Determining the exact lines where the surge levels shift is nearly impossible with the underlying data. As a result, the averages of expected surges were calculated for each zone.

Figure 3-4. SLR regions and data availability. Due to its complex coastal geography, Louisiana is not part of the dataset.



3.5.2 Community infrastructure assumptions

3.5.2.1 Community infrastructure within 40 miles

While an installation may not be located on the coast, it may rely on coastal ports or regional coastal infrastructure for supplies. A threshold of 40 miles was selected as it incorporates the regional dependency of an installation. The Comprehensive Evaluation of Projects with Respect to Sea Level Change (CESL) tool, which analyzes USACE Civil Works sites' vulnerability to climate change, uses a distance of 40 miles. Additionally, 40 miles is the distance used in the Army Stationing and Installation Plan (ASIP) to capture those who live off-base and commute. Therefore, the 40-mile threshold may be used to capture the community and infrastructure that service members are presumed to rely on. Finally, a 40-mile threshold recognizes that installations are situated within regions, and depend on the surrounding region for services and will be affected by what occurs within the region.

3.5.2.2 Community infrastructure location

To calculate the community infrastructure at risk of destruction from SLR, inland flooding, and storm surge, point data from the Homeland Security Infrastructure Program (HSIP) Gold 2012 dataset representing the addresses of community infrastructure were obtained. These data simply represent the X-Y location of a site and do not account for building size or multiple buildings on a property (i.e., a school campus with multiple buildings). A school's street address may not be located in an area that is susceptible to flooding while in actuality a large portion of the facility may be located within a flood zone. Rather than selecting infrastructure located directly in a flood zone, the infrastructure located within 300 ft of the flood hazard was selected. An obvious limitation of this method is a lack of elevation data since an address may be located within 300 ft of flooding, but is directly uphill and therefore does not risk being flooded.

3.5.2.3 Summary of infrastructure at risk nationally

Flooding—whether from SLR, storm surges, or inland flooding events—will affect infrastructure surrounding U.S. Army installations. Table B-1 (in Appendix B to this report, p 101) summarizes the categories of infrastructure at risk of destruction for Army installations nationally. The majority of the infrastructure identified in this analysis as "at risk" are non-emergency community services such as churches, nursing homes, daycare centers, libraries, and public schools. While exact percentages vary between scenarios, they comprise about 70% of the total infrastructure at risk. This large percentage of the total risk is understandable as many communities will have many of these service facilities. This analysis uses a percent of infrastructure at risk, which creates a bias toward certain facility types (like churches and daycares) that are more commonly located within communities.

Table 3-1 lists community infrastructure nationally that is at risk of SLR and flooding. The table demonstrates that more non-essential facilities will be affected than essential services. However, the disruption of certain facilities like electricity generation plants or fire stations will have tremendous impacts on an installation and its region.

Table 3-1. Community infrastructure at risk from SLR and flooding.

	SLR 2050		SLR 2070		100-year Flood Zone		500-year Flood Zone	
Infrastructure Category	# of Assets	% Total*	# of Assets	% Total	# of Assets	% Total	# of Assets	% Total
Places of Worship	293	7.9%	315	8.0%	4,350	9.2%	4,226	10.0%
Blood and Organ Banks	26	0.7%	26	0.7%	207	0.4%	169	0.4%
Colleges and Universities	67	1.8%	70	1.8%	658	1.4%	719	1.7%
Day Care Centers	824	22.2%	880	22.4%	11,567	24.6%	11,500	27.2%
Electricity Generation	28	0.8%	28	0.7%	116	0.2%	29	0.1%
Emergency Medical Service	441	11.9%	478	12.2%	5,729	12.2%	3,891	9.2%
Fire Stations	159	4.3%	174	4.4%	2,555	5.4%	1,243	2.9%
Hospitals	52	1.4%	57	1.5%	534	1.1%	482	1.1%
Law Enforcement	326	8.8%	345	8.8%	3,391	7.2%	2,510	5.9%
Libraries	467	12.6%	489	12.5%	4,262	9.1%	3,441	8.1%
Nursing Homes	562	15.1%	563	14.3%	5,179	11.0%	5,481	13.0%
Public Schools	398	10.7%	429	10.9%	7,603	16.2%	7,833	18.5%
Solid Waste Landfills	29	0.8%	30	0.8%	251	0.5%	114	0.3%
Urgent Care Facilities	29	0.8%	30	0.8%	536	1.1%	552	1.3%
Veterans Health Administration	9	0.2%	10	0.3%	111	0.2%	97	0.2%

# of Assets: Number of infrastructure in category within 300 ft of scenario
*% Total indicates the percentage the category accounts for of all infrastructure at risk in the given scenario

3.5.2.4 Summary of inland flood risk for case study sites

With the possible exception of Fort Wainwright (where data are incomplete), each of these case study installations is vulnerable to infrastructure destruction from inland flooding. Using the flood hazard layers for the 100-year and 500-year horizon, the number of community assets located in these flood zones (summarized in Table 3-2) was selected. As demonstrated in the table, the vulnerability to inland flooding is not distributed equally among installations with assets at risk in the 100-year flood zone ranging from one (Fort Drum) to 170 (Fort Bragg).

The values developed by this analysis are biased toward urbanized areas, where there is a higher concentration of community infrastructure to service the larger population. Picatinny Arsenal (New Jersey) and Fort Hamilton (New York) have the greatest vulnerability with over 2,000 instances of infrastructure located within the 100-year flood zone and another 2,000 in the 500-year flood zone.

Table 3-2. Community infrastructure surrounding an installation located within the 100-year and 500-year flood zone.

Installation Name	State	Infrastructure in 100-yr Flood Zone	Infrastructure in 500-yr Flood Zone*	MV	% Total Infrastructure in 500 Year Flood Zone**
Fort Wainwright***	AK	–	–	1	0%
Fort Drum	NY	1	1	3	0%
Fort Riley	KS	42	55	13	9%
JBLM	WA	58	74	20	1%
Fort Bliss	TX	100	168	32	20%
Schofield Barracks	HI	166	217	39	65%
Fort Bragg	NC	170	322	50	11%

*500-year flood zone indicates the sum of infrastructure within the 100- and 500-year flood zone Federal Emergency Management Agency (FEMA) layers.

**Indicates the number of community infrastructure in the 500-year flood zone sites within 40 miles of an installation/ the total number of community infrastructure sites.

***The majority of the 40 miles surrounding the installation are located in the counties that are not included in the FEMA flood hazard dataset.

3.5.2.5 Inland flooding risk: Fort Bragg

Fort Bragg has the highest amount of infrastructure assets located within the 100- and 500-year flood plain of these case studies, with 322 sites located within 300 ft of the flood plain. This analysis found that there are six urgent care facilities within 300 ft of the 100-year flood zone. However, due to Federal legislation regarding construction in the 100-year flood plain, these facilities may not be at risk of flooding. Localized analysis looking at elevation and building footprints may be useful to determine if these facilities are actually at risk of flooding. Of particular concern is the Cumberland Community Landfill, which is located in the 500-year flood zone. Flooding of this landfill may cause contaminants to spread throughout the region affecting groundwater supplies.

3.5.3 Results: Lost land from storm events

Ten installations may lose land from SLR. A full table outlining these impacts at the seven case study installations is available in Table B-2 (in Appendix B to this report, p 101). Of the case study sites, only JBLM may lose land from SLR by 2070. Due to the installation's location on an estuary, the land lost from SLR will be about 2 acres or 0.003% of total installation size. Analysis of the SLR data reveals that the majority of the extra inundation is a small buffer ranging from 1-10 ft beyond the current inundation level. The additional acreage is from a small area of ponding amounting to

about 0.4 acres, which is not currently inundated, but is expected to be by 2050. Analysis of satellite imagery reveals that this area is currently forested; flooding of this area is expected to have minimal effect on the installation. Table 3-3 lists the risk of land loss from SLR for the case study installations.

3.5.4 Reproducibility of results: Sea Level Rise

This work's SLR analysis is reproducible. Furthermore, by using two compatible sources of SLR information for these future rise projections, the reliability is demonstrated within these results. The validity of the SLR projections is as yet unclear since only the future will demonstrate how SLR will occur (Lowe and Gregory 2010). In particular, the reliability and validity of SLR analysis decreases with scale, as localized factors cannot be accounted for in as much depth.

Table 3-3. Risk of land loss from SLR for case study installations.

Installation Name	2050 Acres Lost	2050 % Lost	2070 Acres Lost	2070 % Lost
JBLM	2	0.01%	2	0.01%
Fort Bliss	–	0%	–	0%
Fort Bragg	–	0%	–	0%
Fort Drum	–	0%	–	0%
Fort Riley	–	0%	–	0%
Fort Wainwright	–	0%	–	0%
Schofield Barracks	–	0%	–	0%

4 Climate Change Impacts on COBRA Costs

4.1 Overview of COBRA

The COBRA model accounts for recurring and one-time costs including environmental and waste management. One recurring cost COBRA accounts for is BOS costs. The water-related BOS costs are water services; waste water services; and snow, ice, and sand removal (Office of the Assistant Chief of Staff for Installation Management (OACSIM) 2013, 13). The BOS costs provide an estimate of the cost of operating an installation.

4.2 The effect of climate change on costs

Changes in the hydrologic cycle will result in significant costs to installations from damage to outdated infrastructure, rising water rates, and infrastructure upgrades. Some of the costs Army installations may incur because they need to adapt their infrastructure are those related to:

- *Ensuring potable water*. A lack of potable water resulting from overtapped aquifers and SLR may require the construction of desalination plants. California American Water is pursuing the construction of a $140 million desalination plant in Monterrey, CA, and estimates that because of the cost of constructing and operating the desalination plant, water bills will increase by 40% between 2013 and 2018 in the Monterrey area (California American Water 2014).
- *Updating sewer systems*. The USEPA Office of Water (2008) says that many water utility districts may not be able to handle the increased storm water load resulting from increased precipitation. Currently, the country's drainage infrastructure is overwhelmed during heavy precipitation and high runoff events (Geogakakos et al. 2014). Until infrastructure is improved, downstream users of combined sewer systems will bear additional costs in water treatment following storm events. The USEPA's 2008 Clean Watersheds Needs Survey found that nationally it will cost $63.3 billion for Combined Sewer Overflow (CSO) corrections (USEPA 2014b).
- *Replacing infrastructure*. Infrastructure such as roads and bridges were built to withstand specific hazards such as a 24-hour rainstorm or a 100-year flood. Storms that exceed the expected intensity can shorten the lifetime of this infrastructure, resulting in costly repairs or replacement (Burkett and Davidson 2012).

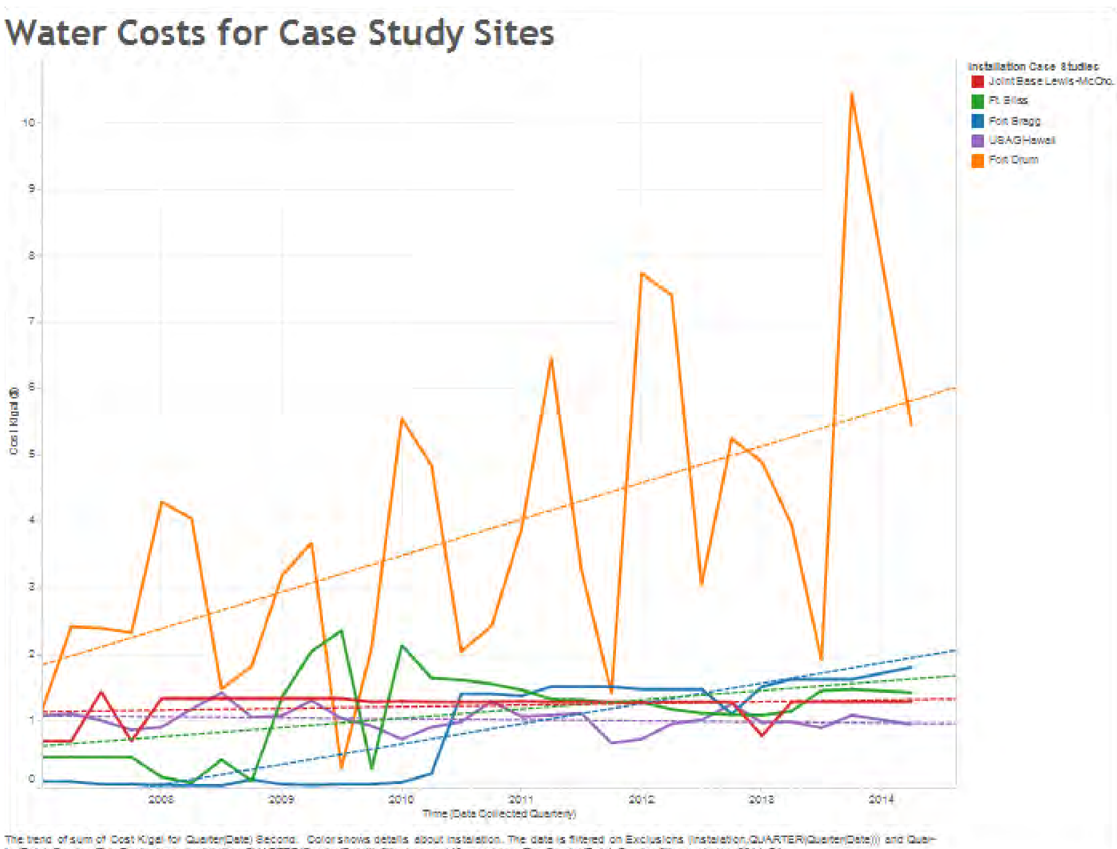
- *Storm damage*. Massive storm events, the frequency of which will increase because of climate change, damage infrastructure, which is costly to repair.

4.3 Methodology for water cost analysis

4.3.1 Water costs limitations and assumptions

Current analysis of BOS costs assumes that future (recurring) costs will be the same as current costs. However, water costs can vary widely. Data from the Army Energy and Water Reporting System (AEWRS) were used to formulate 2007-2014 as a baseline to project water unit costs into the future. The trend line (shown in Figure 4-1) indicates that water costs did not increase linearly. Spikes in unit water costs between 2007 and 2014 may have been the result of temporary price spikes for infrastructure improvements. If so, future unit water cost increases will not happen at the same rate.

Figure 4-1. Water costs for case study installations.



The price data from 2007-2014 used in the analysis do not cleanly fit a trend line, as measured by R-squared (R^2). R^2 is a statistical measure of how closely a dataset is represented by a fitted regression curve. If there were perfect correspondence between a given dataset and a proposed regression curve, R^2 would be 1. As shown in Figure 4-1, the R^2 for the case study installations purchasing water ranges from 0.03 - 0.75, with an average R^2 for the case study installations of 0.27. This indicates that the unit water cost increase data do not fit straight line curves.

4.3.2 Water costs

4.3.2.1 Summary of water cost results

If current pricing increases remain consistent, the unit water costs at many installations will increase by mid-century. Of the seven case study installations, between Q2 of 2007 and Q2 of 2014, it was found that there was a 56% increase in the costs paid per 1,000 gallons, not accounting for inflation. Many possible factors contribute to unit water cost increases, including: planned infrastructure upgrades, system cost recovery due to outdated infrastructure, and the fact that an installation's water consumption might fall below some threshold usage level that would put the installation into a lower volume category at a higher unit cost. The price increases may have been driven by installations reducing their potable water consumption as reductions in water use often drive up unit prices. Installations have been reducing water consumption Army-wide to comply with Executive Order (EO) 13514 (White House 2009), which requires a 26% reduction in potable water use and a 20% reduction in industrial, landscaping, and agricultural water use by 2020 relative to 2007 usage levels (Army Energy and Water Management Program 2014).

However, water conservation alone does not explain the increase in unit water costs, which rose by an inflation-adjusted 53% between 2007 and 2013:

- For the case study installations potable water use declined 7.33% between 2007 and 2013, while costs for potable water increased 76.15% (52.29% with inflation adjustment).
- Fort Bragg had the highest increase in water costs, which increased over 1700% as costs went from an inflation-adjusted $0.10 in 2007 to $1.81 in 2014.

- Fort Riley and Fort Wainwright do not rely on external water sources, but instead rely on groundwater on their installations. These installations do provide water treatment, which has an energy consumption cost, and which is thereby not included in the AEWRS dataset.

4.3.2.2 Reproducibility of water cost results

The availability of the Water Cost data from AEWRS provides a simple national analysis of installation water costs (Table 4-1). As the preceding analysis demonstrates, the water costs produced through the analysis are unrealistic. For the seven case study installations, the R^2 ranges from 0.03-0.75 with an average R^2 for all of the case studies at 0.27. This low R^2 indicates that the data do not fit the regression line, nor do they account for spikes in unit water costs in future years. The current analysis does not account for inflation, and some of the issues with forecasting may be removed by adjusting each year's costs to reflect the cost in 2014 dollars.

Table 4-1. Water cost forecast for case study installations developed using quarterly cost per Kgallon in the AEWRS database. The costs reflected here are in 2014 dollars and are not adjusted for future inflation.

Installation	Water Cost per K/gal			
	2014 Q2	2037	2050	2070
Fort Bliss	$1.43	$3.79	$5.60	$9.08
Fort Bragg	$1.81	$6.32	$10.05	$17.24
Fort Drum	$5.46	$14.32	$21.45	$32.42
Fort Riley	$0.00	$0.00	$0.00	$0.00
JBLM	$1.29	$1.72	$2.05	$2.69
Fort Wainwright	$0.00	$0.00	$0.00	$0.00
U.S. Army Garrison (USAG) Hawaii	$0.95	$0.72	$0.52	$0.12

5 MVA Attribute: Water Quantity

5.1 Background

The Water Quantity attribute used in BRAC ’05 was an analysis of the water withdraws from an installation and the water the installation had rights to withdraw. This analysis presumed that:

1. Water is a static resource and that the current supply will continue to be available during the 20-year horizon of the BRAC.
2. Because an installation has rights to the water, it will be able to exercise those rights.

Water supplies are experiencing increased pressure and are affected by many factors including urban sprawl, climate, water withdrawal rates, and drought (Geogakakos et al. 2014). To improve the calculation of present Military Value of Installations, two additional factors were included in the MVA analysis:

1. Present water stress
2. Water quality.

This water analysis explores how consumption (the current metric) relates to natural forces like reduced water supplies from climate change.

5.2 Water resources

5.2.1 Possible climate change impact on water resources

Climate change may reduce water resources in some portions of the United States, diminishing the amount of water available for Army use in affected areas. An analysis conducted by the RAND Corporation for the U.S. Army found that water scarcity due to climate change will be one of the key challenges for the U.S. Army in coming years (Lachman et al. 2013). These changes could be the result of a number of phenomena:

- Changing weather patterns could reduce precipitation levels and increase evapotranspiration rates in various portions of the country, resulting in drought conditions. These conditions can be expected to increase irrigation rates in these areas, prompting increased extraction of

water from aquifers. Over time, aquifer levels would be expected to decline, making the Army's access to water more difficult and costly.
- While some portions of the country deal with increased frequency and severity of drought conditions, other areas may experience increased precipitation levels. Severe storm events in these areas could cause increased runoff from agricultural lands and flooding of rivers and streams, impacting quality of water resources.
- Rising sea levels could cause contamination of groundwater in coastal areas, especially as groundwater levels are pumped down.
- Increased overall temperatures will lead to increased snow melt rates and an inability for snow packs to replenish themselves. This could contribute to increased incidents of flooding in the spring and reduced surface water availability in the summers.

5.2.1.1 Justification for updating the Water Quantity MVA attribute

Military installations are already feeling the burden of inadequate water planning. Mountain Home Air Force Base (AFB), ID is running out of water. Forecasts cited in local news media indicate that the area will see the effects of water shortages by 2025 and that the installation may have no water by 2040 (Beeby 2013). The water shortage resulted from regional growth, agricultural water use, and the installation's lack of water rights. Resolving the issue of water for the installation will be costly, and DoD and State of Idaho are working together to secure water rights. In early 2014, Governor Otter signed a bill allocating $4 million to acquire senior priority surface water rights on the Snake River, which will be banked until the installation requires them (Idaho 2014). Mountain Home AFB's case demonstrates the necessity of comprehensive evaluation of water in a region as climate change will exacerbate water stress.

In such situations, what complicates assessments of water availability is the military installations' lack of information in two principal areas: (1) the amount of water they have rights to use, and (2) water quality. In the western United States, water rights will increase in importance as populations grow and as water supplies dwindle. West of the Mississippi River where water is scarcer and irrigation is required for crop production, the Prior-Appropriation doctrine is the foundation of water rights. This doctrine allocates water rights based on the mining principal of "first in time, first in right." Through the doctrine, a person obtains a right to a specific quantity

of water that is diverted from the public water supply for use in a fixed geographic area. In contrast, in the eastern United States where water is more plentiful, the doctrine of riparian buffers is used. The riparian buffer doctrine applies to all bodies of water and grants to all riparian owners the right to make reasonable use of the water as long as the water use does not interfere with the reasonable use of water by other users (Grid and Beaulieu 2010; Gopalakrishnan, Tortajada, and Biswas 2006).

Lands removed from the public domain by the Federal government for certain purposes (such as military installations) have implied water rights to satisfy the reservation's purpose. The 1908 Supreme Court case *Winters v. United States* set the precedent that when the Federal government removed land from the public domain for Native American reservations it implied rights to sufficient water. The Winters Doctrine was further clarified in 1976 in *Cappert v. United States*, which determined that Federal lands were entitled to water through reserved rights only if it supported the primary purpose of the reservation. Cappert determined that the Winters Doctrine applied to both surface and groundwater (Jenicek et al. 2009). Reserved rights are, for the most part, immune from state water laws and are therefore not subject to diversion and beneficial use requirements and cannot be lost by non-use.

While the Winters Doctrine provides water rights to installations, in many cases, those rights have not been defended and installations may no longer be able to claim the water rights due to negligence. The Department of the Army cites that a large factor in this is a lack of education in the military concerning water rights (DA 1996). At some installations, neither the Staff Judge Advocate, the Director of Engineering and Housing, nor the Director of Public Works recognized the importance of protecting water rights. Consequently, little emphasis was placed on maintaining records necessary to protect those rights (Stockdale and Johnson 1995).

5.2.1.2 *Summary of proposed updates to the Water Quantity MVA attribute*

- Despite the importance of understanding water rights and recognizing that future water supplies will shift as a result of climate change, the current MVA process presumes that water is a constant. To improve the calculation of present Military Value of Installations, two additional metrics were evaluated for inclusion in the *Water Quantity* MVA attribute:

1. *Water Consumption Stress Index (Present)*. BRAC 2005 examined the amount of water an installation used in relation to its water rights. Using an index of current water stress, adapted from Roy et al. (2012), the regional water stress of CONUS installations was identified. This analysis identified areas of existing water stress and identified areas where an installation may compete with the surrounding region for water.
2. *Water Quality*. The BRAC 2005 *Water Quantity* MVA attribute lacked an analysis of water quality since it presumed that all water is potable. Using data from the USEPA, areas designated as polluted (impaired) waterways under Section 303(d) of the CWA were identified. The proposed updated *Water Quantity* MVA attribute includes a metric for impaired waterways, which is an indicator of degraded water quality.

5.2.1.3 Calculation method: Water Consumption Stress Index (present) metric for Water Quantity MVA attribute

The Water Consumption Stress Index demonstrates the current vulnerability of an installation to water stress. The analysis identifies regions with current water consumption stress that may be unable to provide the water necessary to support an installation. Reductions in water availability impact the strategic capacity and capabilities of an installation (Saylor 2014). By proactively identifying installations with current water consumption stress and incorporating this into stationing analyses, the future MV of installations will be preserved.

This Water Consumption Stress Index calculation is based on a methodology used in a widely cited study conducted by the consulting firm Tetra Tech for the Natural Resource Defense Council (Roy et al. 2012; Spencer and Altman 2010). Although developed for future water stress (2050), the methodology also applies to current water stress. Using 2005 water withdrawal data from the U.S. Geological Survey (USGS) (Kenny et al. 2009) and historic rainfall data from Climate Wizard (Girvetz et al. 2009), three metrics that provide a context related to water consumption stress were calculated:

1. *Extent of Development of Available Renewable Water*:
   (Total freshwater withdrawal (2005)/total available precipitation)*100 [percent]
2. *Susceptibility to Drought*:
   Available precipitation (i.e., precipitation – potential evapotranspiration) in summer months (June, July, August) – water demand (e.g., irrigation, thermoelectric) in summer (June, July, August) [in inches]

3. *Groundwater Use*:
   (Groundwater withdrawal / total freshwater withdrawal) *100 [percent]

Appendix C to this report includes the full methodology. The outputs from these formulas were normalized using:

$$Z = \frac{X-\mu}{\sigma} \tag{5-1}$$

where:

μ = mean
σ = standard deviation.

to have a mean of zero and a standard deviation of one, resulting in values at the county level that followed the same distribution and thus the same scale. More on the standardization can be found in Appendix C, Section C.2 (p 108). This process allowed various data inputs to be compared. These three scores were then summed to provide a composite score for each county.

5.2.1.4 Analysis of data sources used for Water Quantity MVA attribute

5.2.1.4.1 Water quantity data: 2005 National Water Use Information Program

This analysis of current water use relied on the 2005 National Water Use Information Program report, the most comprehensive data on water use in the United States. These data have been collected every 5 years since 1950, and are available for download through the USGS website *Water in the United States* (USGS 2014). The data collected provide estimates of surface and groundwater withdrawals as well as fresh and saline withdrawals in the following categories: industrial self-supplied, irrigation, livestock, aquaculture, mining, domestic self-supplied, thermoelectric, and public water supply water withdrawals (Kenny et al. 2009). This analysis used the 2005 water data, as the 2010 data release was delayed until November 2014 (USGS 2014).

5.2.1.4.2 Water quantity data: Military data call

This work relied on the data supplied in Q825 and Q826 of the Military Data Call, which were used in the 2005 BRAC to analyze water availability

(CAA 2004a). Data calls are mandatory requests for information from the Office of the Secretary of Defense and provide data for the various stationing models. The information used in the 2005 BRAC analysis is over a decade old (for FY01-FY03). Two factors drove this decision to reference the older data—a low response rate from case study installations and a lack of comparable data.

5.2.1.4.3 Water quantity data: Impaired waterways

TMDL is a calculation of the amount of pollutant that a body of water can receive and still be potable (USEPA Office of Water 2014). Waters with contaminant levels above the set TMDL have a low water quality, and are classified as impaired waters. While the TMDL levels are set on the state level, impaired water sites are monitored and collected by the USEPA. The data are available for free download from the USEPA Water Data website (USEPA 2014a), which is updated multiple times a year.

5.2.1.5 Calculation method: Impaired water metric for Water Quantity MVA attribute

The national impaired waterways dataset (rad_303d) were obtained to analyze areas with impaired waterways. Developed by the USEPA Watershed Assessment, Tracking & Environmental Result group, the dataset contains point, line, and polygon data for all waterways with contaminant loads above the TMDL (USEPA 2014). This research sought to quantify how much area on an installation and in the surrounding half mile was covered with impaired waterways. Four metrics were developed to do this:

4. Acres of impaired water on an installation (A)
5. The percent of the installation's land covered by impaired water (B)
6. Acres of impaired water within a half mile of the installation (C)
7. The percent of acres within a half mile of the installation covered by impaired waters (D).

The Water Quality metric of an installation was calculated using the following formula:

$$4A + 2B + 3C + D \tag{5-2}$$

This calculation was determined as a way to weight two factors. First, the formula weights the total number of acres that are impaired. Secondly, the formula weights the installation itself more than the surrounding half mile.

5.2.1.6 Metric calculation method: Water Quantity MVA attribute

These three metrics—impaired water, water available, and water stress—were inputs to the proposed *Water Quantity* MVA attribute.

$$\text{Water Quantity MVA} = \text{Water Available } (*2) + \text{Water Consumption Stress Index } (*2) + \text{Impaired Water} \qquad (5\text{-}3)$$

in which:

- The *Water Available* figure demonstrates the standardized score of the 2005 BRAC *Water Quantity* MVA attribute results.
- The *Water Consumption Stress* score represents the standardized score of the sum of groundwater use, susceptibility to drought, and available renewable water.
- The *Impaired Water* score relates to the area of water surrounding an installation that exceeds contaminant loads as measured by TMDL.

Water Available and *Water Consumption Stress* were given double the weight of the *Impaired Water* metric as they relate directly to the current water availability while impaired water relates to water quality that may not directly relate to available potable water.

5.2.2 Limitations to updated *Water Quantity* MVA attribute

1. *Potability of Water Not Fully Considered*. The proposed *Water Quality* metric considers TMDL and the implications they may have on reductions in installation capacity through legally mandated reductions in runoff and discharge into streams. This metric does not consider whether water was safe for use. The safety of water is captured through the Federally mandated Water Quality report. This report, which all water providers (including Army installations) produce annually, documents contamination within the supply. For example, if one well on an installation has become contaminated and has been removed from service for remediation, under current reporting methods that water would still be included in the total

amount of water available. As this water is not usable or safe, it should not be part of the installation's water rights.

2. *Water Rights*. If installations in the western United States rely on water sources that are not located on the base, then additional analysis to understand where they fall in the hierarchy of water rights should be performed. This analysis presumes that the installation will have access to its full water rights, but in drought years an installation may have reduced water access as users with higher priority rights consume the water. The Winters Doctrine guarantees access to water located on an installation through sovereign powers. Additionally, installations purchasing water are subject to restrictions created by the local water utility. In 2013, Fort Carson reduced its water use by 30% in response to mandatory restrictions by the Colorado Springs Utilities taken in response to drought (Galentine 2013).
3. *Discrepancy in Use Data*. This analysis relied on data provided in the 2005 BRAC. Question 826 of the 2005 Military Data Call requested the average daily water use in millions of gallons per day (MGD). The data call did not specifically ask if this average daily water use counted greywater that was recycled for other purposes on the installation. In Colorado and some other western states, recycled water counts toward water taken from a water right. Fort Carson has to pay the Colorado Springs Utilities for each unit of recycled water used.

5.3 Water analysis results

5.3.1 Water consumption stress index results

Counties across the United States are experiencing water consumption stress that will become more extreme as their populations grow and as the climate changes. The data in Table 5-1 indicate that the number of counties with extreme water consumption stress in the United States is expected to grow 90% between 2005 and 2050. Between 2005 and 2050, the number of counties with Extreme Risk or High Risk to water consumption stress will grow by 489 counties. As a result of population pressure and climate change, a number of counties from the Moderate Risk category will shift to having High Risk by 2050. Three water-related metrics in two indices were used to calculate the water consumption stress of regions: (1) extent of development, (2) summer precipitation deficit, and (3) groundwater use. The full methodology on calculating these indices is provided in Appendix C, Section C.4 (p 110).

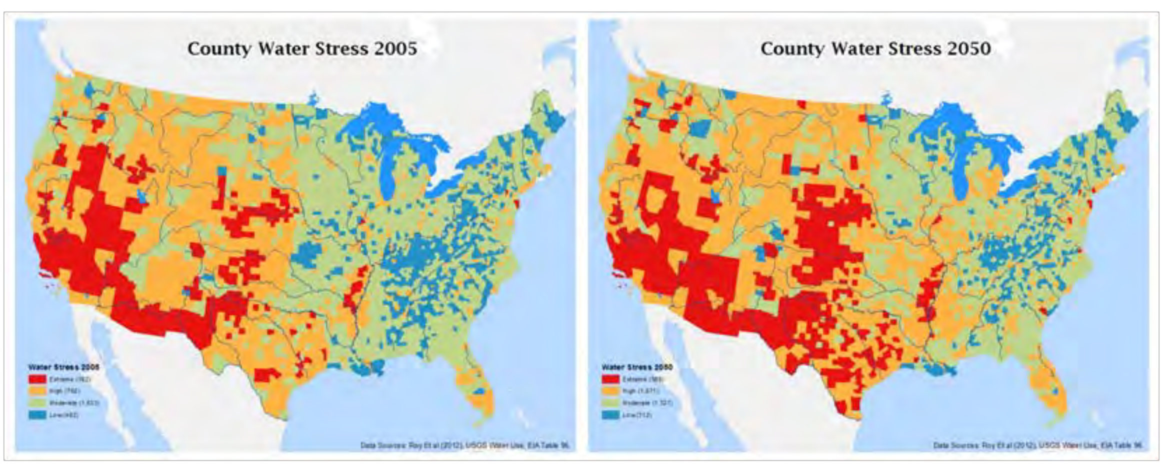
Table 5-1. Summary of county water risk in 2005 and 2050.

Risk Type	Number of Counties 2005	Number of Counties 2050	Shift 2005 to 2050
Extreme Risk	192	369	+177
High Risk	763	1,072	+309
Moderate Risk	1,633	1,327	-306
Low Risk	492	312	-180

First, a national county assessment was developed that ranks counties' risks to water consumption stress as Low, Moderate, High, and Extreme using thresholds supported in the literature. Secondly, a score of relative vulnerability (the sum of the standardized values of the raw values) was developed. This second score allowed installations to be ranked based on their specific risks relative to other installations. More on standardization can be found in Appendix C, Section C.2 (p 108).

This analysis found that many regions of the United States have extreme or high risk to water consumption stress and it is likely that demand will exceed the supply in these areas. The water consumption stress indices for 2050 and 2079 (Figure 5-1) show that many parts of the United States are already experiencing "extreme water consumption stress," which is defined as having high groundwater use, using more water than falls as precipitation, and having a summer precipitation deficit. This analysis demonstrates that the water consumption stress of the United States will increase as a result of climate change and growing populations. The majority of the stress is concentrated in the southwest United States and near the Ogallala Aquifer.

Figure 5-1. Water Consumption Stress indices for 2050 and 2070.



The states of California, New Mexico, Nevada, Utah, Arizona, Texas, and Oklahoma account for 53% of the counties that will have extreme water consumption stress in 2050. Only 12 counties east of the Mississippi River are expected to have extreme water consumption stress in 2050. The water consumption stress of the U.S. Army follows a similar distribution as the rest of the United States for both the 2005 and 2050 horizons. Counties surrounding the Ogallala Aquifer, which stretches from Oklahoma to Texas, demonstrate extreme risk. This aquifer provides freshwater for about 20% of America's wheat, corn, cattle, and cotton and is being depleted faster than it can be recharged by rain. Texas Tech researchers have found that in some places, the water table is dropping by as much as 2 ft/yr (True 2007). Researchers in the Kansas portion of the Ogallala have determined that about 30% of the aquifer has already been used up and another 39% will be used up in the next half century with current use rates (Steward et al. 2013).

This analysis, consistent with others' work, finds that climate change will increase the risk that water supplies will be unable to keep pace with withdrawals (Spencer and Altman 2010; Roy et al. 2012). Increasing water use for electricity generation is one of the drivers of water consumption stress. For example, in 2070, the increases in water withdrawals for thermoelectric electricity generation accounted for 55% of the total water withdrawals. Water withdrawals for thermoelectric generation in 2070 account for 74% of total withdrawals (ERDC-CERL analysis). Areas may be able to reduce their risk to water consumption stress by using less water intensive electricity generation practices.

5.3.1.1 Water consumption stress indices for CONUS case study sites

Climate change and population growth will lead to greater water stress in 2050 at Fort Bliss and Fort Riley while the stress will remain the same or drop at JBLM and Fort Bragg. The case study data in Table 5-2 indicate that Fort Bliss is the only installation with extreme water stress in either 2005 or 2050.

Table 5-2. CONUS case study installation water stress risk.

Installation Name	Stress Score 2005	Stress Category 2005	Stress Score '50	Stress Category '50
Fort Bliss	5	Extreme	6	Extreme
Fort Bragg	1	Moderate	1	Moderate
Fort Drum	1	Moderate	2	Moderate
Fort Riley	2	Moderate	3	High
JBLM	3	High	2	Moderate

5.3.1.1.1 Water consumption stress analysis: Fort Bliss

Fort Bliss experiences some of the highest water consumption stress in the United States both in current conditions and as a result of climate change. In response to the arid climate, a growing population and the intensive water needs of the installation, the El Paso Water Utilities (EPWU) and Fort Bliss jointly operate the $91 million Kay Bailey Hutchison Desalination Plant, which turns brackish groundwater into drinkable water. The plant can produce 27.5 million gallons of freshwater a day.

One factor pushing Fort Bliss' water consumption stress in coming decades is electricity generation in two surrounding counties, El Paso and Doña Ana, which are expected to increase their water withdrawals for electricity generation. While these two counties produce a small percentage of the electricity generated in the Electricity Market Module (EMM) region* and therefore this work's forecast of the increase in future electricity generation is low, it is expected that withdrawals for electricity generation will increase.

The largest factor contributing to Fort Bliss' extreme water consumption stress in both 2005 and 2050 is the arid climate. While the region presently receives minimal rainfall, the amount of rain falling is expected to decrease while temperatures rise as a result of climate change. This is expected to lead to an increase in evapotranspiration, i.e., the sum of evaporation and plant transpiration to the atmosphere. An increase in evapotranspiration reduces the amount of surface water available (Foti, Ramirez, and Brown 2012; Spencer and Altman 2010).

* EMMs are accounting units developed by the EIA and relate roughly to the North American Electric Reliability Corporation (NERC) regions.

5.3.1.1.2 Water consumption stress analysis: JBLM

JBLM's water consumption stress score drops from "High" in 2005 to "Moderate" in 2050 because climate change is expected to temporarily increase precipitation in the region. This increase is expected to just be in the short term, as climate models predict that by the end of the century the Pacific Northwest will be drier than current conditions (Walsh et al. 2014).

The region primarily relies on surface water for potable water. As a result, issues of aquifer depletion, which may affect water supply, are not an issue in the region. The reliance on surface water may be an issue at the end of the century as precipitation levels fall.

5.3.1.1.3 Water consumption stress analysis: Fort Riley

Fort Riley's water consumption stress vulnerability shifts from moderate to high between 2005 and 2050. The increase is attributed to an increased susceptibility to drought because of reduced precipitation and increased evapotranspiration. Furthermore, the Flint Hills Region surrounding Fort Riley has very high groundwater use. Both Riley County and Geary County, which surround the installation, rely on groundwater for over 95% of their withdrawals. This is more than double the national average of 45% (Kenny et al. 2009).

5.3.1.1.4 Water consumption stress analysis: Fort Drum

The vulnerability of Fort Drum to water consumption stress is expected to increase slightly between 2005 and 2050. The area is expected to have an increase in precipitation (2.66 in.) that may negate projected regional growth. The region uses a small amount of the total available precipitation and does not rely heavily on groundwater to meet local needs. The installation itself, however, does rely on groundwater to a higher degree than the surrounding community.

Responses to ERDC-CERL questions in July 2014 indicated that the installation has four wells currently in use. Five additional wells have been constructed and are awaiting approval from the New York State Department of Health. Currently about 40% of the installation's water comes from the wells on the installation and this will increase as a result of opening the additional wells (Rowley 2014). Increasing groundwater dependence will reduce water supply costs, as Fort Drum paid the highest costs for water of

these case study sites, with an average quarterly cost of $3.79/kgal. In Q2-Q4 of 2013, Fort Drum paid over $7.40 per 1,000 gallons of water. Increasing reliance on groundwater may cause regional stress in the long run, but the shift reduces the costs to the installation in the short term and the minimal reliance on groundwater in the region indicates that the installation's reliance will not stress the water supply.

5.3.1.2 Reproducibility of Water Stress Index

The Water Consumption Stress Index is reproducible; the greatest challenge in the reproduction is modifying the index to a national scale to include Alaska and Hawaii. As a test of feasibility of the analysis and to see if the results were significant, the current analysis opted for easily accessible climate data that were only available for CONUS. While new data sources for climate data would need to be acquired, these exist and can be leveraged by a climate expert to extract needed climate metrics. Therefore, while the current analysis was not conducted at a national level, it would be possible to do so. The current water use data are collected for Alaska and Hawaii.

5.3.2 Water Quantity (MVA results)

The *Water Quantity* MVA attribute is a test of the availability and potability of water near an installation. This attribute was updated from the 2005 attribute to include a region's current water consumption stress as well as data on contaminated water within the region. Expanding the definition of water as it relates to MV revealed shifts in the ranking of installations. This analysis focused on 72 installations examined in BRAC 2005.* This analysis had two main conclusions:

1. Installations may report having entitlements to large amounts of water, but may be located in water stressed areas indicating that they may not be able to access their full entitlement.
2. Inclusion of impaired waterways highlights installations with water quality issues. This may affect potable water supplies or the ability for the installation to fulfill its mission.

* The following installations were analyzed in BRAC 2005, but for a variety of reasons were excluded from this analysis: Crane Army Ammunition Activity, Fort Greely, Fort McCoy, Fort McPherson, Kansas Army Ammunition Plant, Lima Army Tank Plant, Louisiana Army Ammunition Plant, Natick Soldier Systems Center, U.S. Army Garrison Selfridge, Lake City Army Ammunition Plant

There are shifts in scores between the MVA attribute used in 2005 and the proposed update. The data in Table 5-3 describe shifts in the Water Quantity MVA rank for the case study sites, which reflect the water consumption information from BRAC 2005. A ranking of 1 indicates the highest MV, while higher numbers indicate lower MV and that the installation has high water stress. Positive changes in rank indicate that with the new metric, the MV of the installation has increased.

The Total Score column, which indicates the proposed MVA value for each installation, is calculated as follows:

$$\text{Available Water } (*2) + \text{Water Stress Index } (*2) + \text{Water Quality} \qquad (5\text{-}4)$$

The New Rank column indicates how the installations rank nationally using this proposed updated analysis, while Rank 2005 is the ranking of the installations in the 2005 BRAC. Lower ranks indicate higher MV, with 1 indicating the highest MV.

In 2005, both Fort Bragg and Fort Lewis consumed more water than they had rights to consume. As a result, both have a 2005 ranking of 58, which is the ranking of least value to the U.S. Army. With the new analysis, their ranks are 12 and 26, respectively. Fort Bliss and Fort Riley conversely used less water than they had rights for and in 2005 both installations were ranked as having the greatest value to the U.S. Army. Both Fort Bliss and Fort Riley's MVs were reduced in rank through the new analysis at 9 and 3, respectively.

Table 5-3. Results of updated *Water Quantity* MVA attribute.

Installation	*Water Quantity* MVA Attribute for Case Studies						
	Available Water*	Water Stress Index**	Water Quality (TMDL)	Total Score	New Rank	Rank 2005	Change in Rank
Fort Bliss	2.20	-0.27	-0.75	3.10	9	1	-8
Fort Bragg	-0.77	1.18	1.31	2.12	12	58	46
Fort Drum	-0.33	0.36	-0.75	-0.69	39	35	-4
JBLM	-0.77	-0.16	2.53	0.67	26	58	32
Fort Riley	2.20	0.45	0.04	5.35	3	1	-2

*Available water is the standardized score of the 2005 BRAC *Water Quantity* MVA attribute.

**The Water Stress Index was only able to be calculated at this point for CONUS installations

5.3.2.1.1 Analysis of water quantity at Fort Bliss

While Fort Bliss used far less water than they had rights to, that water is not necessarily sustainable. The installation receives water from EPWU, which, in addition to groundwater from aquifers and seasonal water from the Rio Grande, provides water to the installation from the Kay Bailey Hutchison Desalination Plant (Cabe et al. 2012). According to the EPWU website, this plant is the largest inland desalination plant in the world capable of producing 27.5 million gallons of fresh water daily (El Paso Water Utilities 2014). While the plant is able to turn brackish groundwater (which exceeds the freshwater groundwater supply by 600%) into usable water, the process is energy intensive and not sustainable. According to the Texas Comptroller of Public Accounts (2014) the cost to operate the plant is 2.1 times higher than ordinary groundwater extraction in the region because of the extra energy required in desalination. The average cost of production is $1.50 per 1,000 gallons.

Fort Bliss is located in a region identified as having high water consumption stress. Each of the four counties surrounding Fort Bliss has more water withdrawals than available precipitation (Table 5-4). The data in Table 5-4 indicate a high regional water use in relation to available water. For example, Doña Ana County's water use exceeds the available precipitation by over 3,000%.

Despite the desalination plant, the region relies heavily on surface water flows for potable water; the counties' surface water uses range from 7% (Hudspeth County) to 63% (El Paso County). The apparent abundance of water at Fort Bliss led to unsustainable water practices. Analysis conducted by the Pacific Northwest National Laboratory (PNNL) found that because of the perceived abundance of water, Fort Bliss has not cut back on outdoor amenities relying on water. For example, the installation uses large amounts of potable water during the summer for irrigating golf courses and plants (Cabe et al. 2012). Implementation of water conservation measures, such as reducing the amount of outdoor irrigation, could add significant MV to the installation.

Table 5-4. Water use for the four counties that contain parts of Fort Bliss.

County Name	Water Use / Available Precipitation (%, 2005)	Groundwater Withdrawal/ Total Withdrawal (%)
Doña Ana	3,233.61	38.63
Otero	161.78	63.27
El Paso	64.79	36.52
Hudspeth	36.23	92.09

Despite its high water use and location in a water stressed region, Fort Bliss continues to have a high MV with the new analysis, ranking ninth. This is a result of the lack of impaired water on the installation and because of the desalination plant, which provides plentiful water to the installation.

5.3.2.1.2 Analysis of water quantity at Fort Riley

In both the current and proposed Water Quantity attribute, Fort Riley demonstrates a high MV. Fort Riley is located in a region with plentiful water and the installation's water use is modest. Fort Riley is located within a region that can withstand additional personnel. Additionally, the installation currently supplies its own water through a system of subterranean wells. The central water treatment facility produces on average "2 to 3 Mgal per day to meet water demands on post, allowing for significant future growth" (Elam et al. 2012, 1.1).

Fort Riley's slight Water Quantity MVA drop is largely due to the amount of impaired water surrounding the installation (Figure 5-2). The prevalence of this impaired water near the installation can reduce water quality. In fact, much of the water surrounding Fort Riley is contaminated with fecal coliform bacteria. The presence of these bacteria in the surface water supply places a burden on Fort Riley to closely monitor its discharge into surface water. Specifically, Fort Riley must monitor the temperature of the discharge water as the bacteria can spread more quickly in warmer water (Kansas Department of Health and the Environment 2000).

Figure 5-2. Impaired water surrounding Fort Riley, Kansas.

5.3.2.1.3 Analysis of water quantity at JBLM

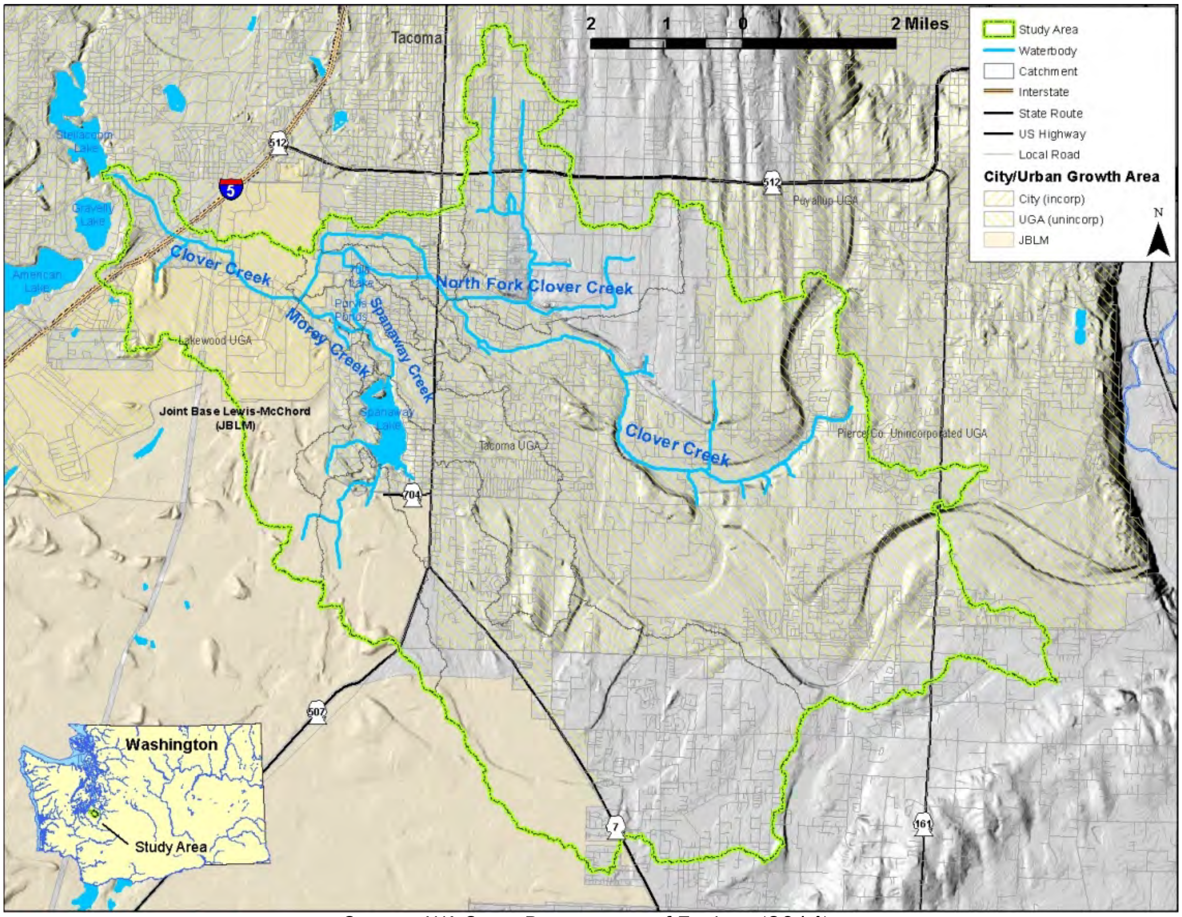
Of the case study installations, JBLM has the lowest value to the U.S. Army based on water availability, ranking 26th nationally. This is a large jump from ranking last (58th) in the 2005 BRAC. This shift can be largely attributed to the moderate water stress in the region. As a result, when JBLM was compared to other installations through the z-scoring of water stress, JBLM received a favorable ranking:

1. *Consumption of more water than the installation has rights to consume.* In 2005, Fort Lewis had a deficit of almost 7,000 gallons of water per day (CAA 2004a). This may no longer be an issue for the installation, as data provided by JBLM in the preparation of this report indicate that with the merging of Fort Lewis and McChord AFB, onsite well capacity has expanded. Various data challenges prevented these updated figures from inclusion in this analysis. As a result, JBLM may not be consuming more water than they have rights to.
2. *Impaired Water*. JBLM is surrounded by impaired water (Figure 5-3). The Clover Creek watershed does not meet State of Washington requirements for dissolved oxygen (DO), fecal coliform (FC), and temperature (WA State Department of Ecology 2014). According to the Washington State Department of Ecology, the area is still being studied and the possible effects on the installation in terms of reductions and remedial actions remain unknown.

5.3.2.1.4 Reproducibility of updated Water Quantity MVA results

The Water Quantity MVA results are reproducible. The results of the analysis could be bolstered by adding another measure of water quality to the analysis, as TMDL does not directly relate to the quality of potable water. To better account for potable water quality, the analysis would be bolstered by using the Clean Watershed Needs Survey alongside the TMDL data. The Clean Watershed Needs Survey is conducted every 4 years by the USEPA's Office of Wastewater Management. The dataset collects data on publicly owned wastewater collection and treatment facilities, stormwater and CSO control facilities, nonpoint source (NPS) pollution control projects and decentralized wastewater management.

Figure 5-3. Impaired waterways and the Clover Creek watershed in Washington state.



Source: WA State Department of Ecology (2014).

6 MVA Attribute: Environmental Elasticity

6.1 Background

Environmental Elasticity was included in the list of MVA attributes used in the BRAC 2005 stationing analysis. This attribute is defined as "the ability for an installation to absorb additional personnel based on the utility resource physical capacity constraints and resource costs at capacity thresholds" (CAA 2014). At the time of the BRAC 2005 stationing analysis, the resources examined were: Training Land, Energy (Electricity and Natural Gas), Water, and Wastewater Treatment and Solid Waste.

6.1.1 Water resources in Environmental Elasticity MVA

The *Environmental Elasticity* MVA attribute defines water in terms of the number of additional Soldiers an installation can support before water capacity is met. This attribute presumes per capita water use will remain constant and measures the ability of an installation to support additional growth. This attribute places a threshold capacity on water supply and treatment, which may be related to treatment plant size, distribution limits, and permit restrictions. The attribute presumes that current water use in regions of interest can be sustained in the future.

6.1.2 Energy resources in Environmental Elasticity MVA

The *Environmental Elasticity* MVA attribute is defined as an installation's ability to absorb varying sizes of units based on additional unit loads and the costs of training land, energy, etc. Here energy is assessed as electricity and natural gas availability and costs. The availability of energy off the installation is assumed to be unlimited (according to the methodology for the attribute). However, there is a threshold at which the electrical capacities of off-post substations and transmission lines are limited. Energy variables used for the *Environmental Elasticity* attribute include:

- peak electricity demand and total annual cost
- electrical capacity of electric substations and transmission lines
- peak demand capacity of substations
- peak monthly usage of natural gas and total annual cost
- natural gas pipeline capacity.

6.2 Summary of analysis

It is proposed that two new metrics be added to the *Environmental Elasticity* MVA. These metrics, which will improve the MVA by better assessing the electrical capacity available to installations, are *Renewable Energy* and *Infrastructure*. The *Renewable Energy* metric is intended to be incorporated in the *Environmental Elasticity* attribute of the MVA process. The *Renewable Energy* metric takes a holistic approach to analyze renewable energy potential by incorporating site-specific political, economic, environmental, and training realities. These characteristics include state incentives and regulations that impact renewable energy. This is an important metric for an Army installation as it indicates the status of an installation's energy security and reduced vulnerability to disruptions to the national energy grid systems.

6.3 Renewable Energy Metric

6.3.1 Justification for the Renewable Energy metric

An installation should be able to self-sufficiently produce energy to improve its energy security, which would result in reduced vulnerability to grid failures and power outages. If an installation does not have the resources to provide its own source of sustainable energy 10, 20, or even 50 years from now, it will be at a higher risk with respect to its energy security. This will potentially reduce the efficiency of current military training and operations, will impact Soldiers' quality of life, and will affect quality of training and work productivity. The *Renewable Energy* metric assesses energy security at installations based on the climate and regional characteristics considered suitable for solar, wind, biomass, geothermal and ground-sourced heat pumps (GSHPs) while also accounting for Mission Compatibility. Assessing the potential to produce, purchase, and consume electricity and thermal energy from renewable sources on an Army installation is a valuable component to consider in Army stationing analyses. The *Renewable Energy* metric proposed in this report measures an installation's relative energy security based on the feasibility of its climate and regional characteristics to generate renewable electrical or thermal energy. The metric includes an assessment of an installation's mission capabilities, ensuring compatibility of training operations and renewable energy technologies. It also considers economic feasibility and energy regulations or incentives, which vary by state. The *Renewable Energy* metric also takes

into account current renewable or alternative energy consumed (purchased or produced on site) by giving a higher rating to installations that use renewable energy. (These data are taken from the AEWRS and Installation Status Report – Natural Infrastructure [ISR-NI] databases.)

Previous energy metrics used for Army stationing analyses consisted of an *Environmental Elasticity* MVA attribute. This metric assessed electricity demand and cost, and electrical grid reliability (the probability that any given element in the infrastructure system is functional at any given time [Murray et al. 2007]). It is recommended that the method used for the *Renewable Energy* metric be included in the MVA stationing analysis. To make this a stronger metric, it can be combined with the vulnerability of energy to natural disasters and the previous *Environmental Elasticity* attribute. Renewable energy should be considered in Army stationing as it can contribute to significant reductions in the overall operational expenditures at Army installations.

Table 6-1 provides basic information about the overall energy consumption (natural gas and electricity), energy use intensity (EUI), energy costs, and changes in these amounts over time at seven case study installations. However, it does not demonstrate what drove those changes. Further research into Fort Bliss, for example, suggests that consumption increased 25% due, in part, to an overall increase in the number of Soldiers at the base. A 2012 report claimed the number of Soldiers at Fort Bliss would triple to about 30,000, resulting in an increase in electricity use of up to 60% between FY10 and FY15 (Galbraith 2012).

6.3.2 Methodology for Renewable Energy metric

The stationing analysis previously included energy and water metrics combined in the *Environmental Elasticity* MVA attribute. Previous versions of this attribute did not consider the Army's vulnerability regarding access to the U.S. electric grid caused by changes in the climate, temperatures and precipitation event impacts on the infrastructure, changes in energy consumption, or sustainable energy alternatives such as harnessing renewable energy.

Table 6-1. Case study installation energy consumption, EUI, and energy cost changes from FY03 to FY13.

Installation	Energy Consumption	% Change Energy Consumption	Energy Use Intensity	% Change in EUI	Energy Costs	% Change
Fort Bliss						
FY 2003	1,252,984		79.26		$15,975,723	
FY 2013	1,502,214	20%	66.59	-16%	$19,968,814	25%
Fort Bragg						
FY 2003	3,093,120		136.08		$29,348,460	
FY 2013	3,478,964	12%	105.32	-23%	$46,349,334	58%
Fort Drum						
FY 2003	1,532,042		104.94		$16,354,484	
FY 2013	1,061,893	-31%	87.64	-16%	$11,564,105	-29%
Fort Riley						
FY 2003	1,359,873		102.39		$11,956,913	
FY 2013	1,199,780	-12%	100.17	-2%	$13,951,048	17%
Fort Wainwright						
FY 2003	3,501,264		454.90		$13,296,974	
FY 2013	2,698,187	-23%	374.97	-18%	$13,873,924	4%
Joint Base Lewis-McChord						
FY 2003	1,779,682		106.61		$11,700,482	
FY 2013	2,298,939	29%	88.79	-17%	$21,028,571	80%
USAG Hawaii						
FY 2003	1,040,430		43.94		$32,227,471	
FY 2013	829,628	-20%	58.70	34%	$62,345,253	93%

Information Source: AEWRS

To improve the stationing analysis, CAA methods should include renewable energy potential and U.S. grid vulnerability to natural hazards. Research for this study did not analyze the vulnerability of other energy sources such as natural gas pipelines or transportation fuel sources. Further research should seek to include these other energy sources. Pipelines and roads, which are the main avenues for transporting natural gas and transportation fuels, are at risk to SLR and flooding that are projected to increase due to climate change. The methods for analyzing renewable energy potential attempt to combine quantitative and qualitative methods. The following steps were used to accomplish this:

1. Gather Resource Abundance, Mission Compatibility and Renewable Energy Potential data for Army installations from the FY12 Annual Energy Management Report (AEMR) produced by the Office of the Deputy Under Secretary of Defense - Installations and Environment (ODUSD I&E).
2. Compile total energy consumption and percent of renewable energy purchased or produced onsite from the AEWRS and ISR-NI databases.

3. Combine the Resource Abundance, Mission Compatibility, renewable energy potential and consumption data to arrive at an overall MV score that characterizes the accessibility of renewable energy.
4. Assign numbers to Resource Abundance and Mission Compatibility ratings. This allows the ratings to be weighted and scored based on their value to support renewable energy sources, where:
   a. Green = 2
   b. Amber = 1
   c. Red = 0
   d. N/A = 0.
5. Sum Resource Abundance and Mission Compatibility scores. For example, the sum for Resource Abundance at Fort Drum using the methods and data shown in Figure 6-1 would be as follows:

   Amber + Amber + Red + Red + N/A

   Replacing the qualitative data with assigned values would result in the following summation:

   1+1+0+0+0 = 2
6. Calculate the renewable energy supply potential versus the total energy consumed on the installation. This is done by dividing the total renewable energy potential (the sum of solar, wind, biomass, geothermal and GSHP, in million BTUs, data from the AEMR) by the total annual energy consumed (obtained from AEWRS).
7. Adjust the score to credit installations that currently purchase renewable energy through Power Purchase Agreements (PPAs), or that are producing renewable energy onsite by adding the percent of energy purchased or produced. A PPA allows the Army to enter into a contract with firms or contractors that operate or maintain renewable or alternative energy generating facilities. These contracts can last for up to 30 years. Data for renewable energy PPAs and onsite generation are located within the ISR-NI reporting system.
8. To arrive at the final renewable energy potential score for the MVA, add the sum of each Resource Abundance, Mission Compatibility, and percent of purchased or produced energy to the supply versus demand.
9. Supply vs. Demand on the Installation is calculated as ($A_1 \div A_0$) and credit for purchasing or producing renewable energy is expressed as (A_2), where:

   A_0 = Total MMBTU of energy consumed (2013 annual data available from AEWRS or AEMR)

A_1 = Total MMBTU potential (solar + wind + biomass + geothermal + GSHP); from AEMR/National Renewable Energy Laboratory (NREL)

A_2 % Renewable Energy purchased or produced onsite (from ISR-NI Energy Security question MS413-9 and ISR-NI Renewable Energy question MS414-1)

(B_0) = Sum of Resource Abundance

(C_0) = Sum of Mission Compatibility

The following formula was used to determine the renewable energy potential for installation energy security:

$$\frac{A_1}{A_0} + A_2 + \frac{B_0}{3} + \frac{C_0}{3} \tag{6-1}$$

6.3.2.1 Resource Abundance

Resource Abundance is an evaluation of political and economic resources, such as regulatory and financial incentives. Installations categorized each of the five renewable energy sources (solar, wind, biomass, geothermal and GSHP) as Favorable, Limited, Not Favorable, or Not Evaluated based on local and regional energy prices and regulatory incentives. This classification is listed in the appendix of the FY12 AEMR (Figure 6-1) as required by the FY10 National Defense Authorization Act, Section 332. The figure shows the categorization and ranking of renewable resources according to Resource Abundance for the seven case study installations. The categories associated with the color rankings are defined in Figure 6-1.

6.3.2.2 Mission Compatibility

Mission Compatibility assesses the overall impacts of harnessing renewable energy to the installation's mission requirements and the overall feasibility of the energy project. For example, Fort Bliss in Texas has an abundant supply of solar radiation. Choosing a suitable location (siting), however, to place photovoltaic (PV) panels is more challenging. Siting the panels near an airfield is incompatible from an aviation standpoint as the PV panels reflect sunlight. This light reflection potentially causes glare issues that interfere with control towers, runways, pilots' vision and flight paths (Shea 2012).

Figure 6-1. Resource Abundance classification in FY12.

DoD Component	Installation	State / Country	Resource Abundance/Economic and Regulatory Environment/Financial Incentives				
			Solar	Wind	Biomass	Gthm	GSHP
Army	FORT CARSON	CO	A	G	G	R	N/A
Army	FORT DETRICK	MD	A	A	A	R	N/A
Army	FORT DRUM	NY	A	A	R	R	N/A
Army	FORT EUSTIS	VA	A	G	A	R	N/A
Army	FORT GEORGE MEADE	MD	A	A	G	R	N/A
Army	FORT GORDON	GA	A	A	A	R	N/A
Army	FORT GREELY	AK	A	R	A	R	N/A

Source: FY12 *AEMR* (2015).
Green = Favorable; Amber = Limited; Red = Not Favorable; N/A = Not evaluated

Additionally, siting wind turbines on installations is challenging as the rotating turbine blades can reflect and diffract radio waves, interfering with radio communication signals (Joint Radio Company 2014) for aviation radars, communication, and other uses. Mission Compatibility was categorized as:

- siting is compatible with little to no interference,
- interference exists, but can be mitigated, or
- siting is incompatible.

Similar to the Resource Abundance evaluation, Mission Compatibility ratings were color coded accordingly:

- Green = Siting is compatible
- Amber = Interference exists, but can be mitigated
- Red = Siting is incompatible
- N/A = Not evaluated

6.3.2.3 *Fort Bliss case study example*

Figure 6-2 lists the numbers derived using this method for Fort Bliss. The AEMR values were taken from the Annual Energy Management Report (FY12). The weighted values are those assigned and detailed in the above methodology. Energy consumed and renewable energy consumed data are from the ISR-NI and AEWRS databases. The final score is the sum of each category after the equation is applied to its respective section.

6.3.3 Analysis of Renewable Energy metric

The renewable energy potential and vulnerability to natural disasters provides a foundation for framing energy security and sustainability. Additional information such as climate change effects on building energy consumption and energy cost impacts are being developed at ERDC-CERL with the intent that these considerations will also be added into installation realignment analyses.

6.3.3.1 *Limitations of the Renewable Energy attribute*

1. *Static Data*. Data for the *Renewable Energy* attribute is derived from the ODUSD (I&E) AEMR (2012). Information about the methods used by NREL and the survey design for the data call are not known. An understanding of how the data were derived for the AEMR is not known. Furthermore it is not likely that these data will be updated within the next few years.
2. *Resiliency of Renewable Energy to Climate Change Risks*. In addition, one report indicated that renewable energy sources tend to be more sensitive to climate metrics (Bull et al. 2007).

Figure 6-2. Example of renewable energy data and application of Equation 6-1.

	Resource Abundance/Economic and Regulatory Environment/Financial Incentives					Mission Compatibility					Rewewable Energy Potential: Estimated Annual Production (MMBtu)					Energy Consumed (MMBtu)	Renewable Energy Consumed (%)
Fort Bliss	Solar	Wind	Biomass	Geothermal	GSHP	Solar	Wind	Biomass	Geothermal	GSHP	Solar	Wind	Biomass	Geothermal	GSHP		
AEMR Values	A	G	A	G	N/A	A	A	A	A	G	42,747	231,067	–	34,600	11,705		
Weighted Values	1	2	1	2	0	1	1	1	1	2	42,747	231,067	–	34,610	11,705		
Total of Weighted Values	6					6					320,129					1,502,214	0.001
Apply Equation	2					2					0.214						
Final Score	4.214																

Note that the numbers listed in Table 6-2 were generated before they were added together for the final MVA score. The potential renewable energy divided by the total energy consumed, plus percent of total renewable energy purchased or produced make up the Renewable Energy Potential Category. Plausibility is the sum of Resource Abundance for each renewable energy source. Compatibility is the sum of Mission Compatibility for each renewable source. Of the case study installations, Fort Drum has the highest measure of energy security based on its current renewable energy use and potential to implement more renewable/alternative energy production or consumption on the base.

Fort Bliss has been selected by the Army as a Net Zero pilot installation in three categories—energy, water and waste. With respect to energy, Fort Bliss has a goal of producing as much energy on site as it uses over the course of a year by 2018. While Fort Bliss enjoys an abundance of solar radiation and potential to use photovoltaic panels and solar thermal panels to move it toward its Net Zero Energy goal, the installation will not be able to meet its Net Zero goal through the use of solar technologies alone. Other technologies, including wind turbines, geothermal wells, and waste-to-energy technologies are being planned to move the installation toward Net Zero Energy.

6.3.3.2 Results of the Renewable Energy metric

Renewable energy potential scores of analyzed installations range approximately from 3 to 8 (Table 6-2). This fits within the standard MVA method that generates scores between 0 and 10. The lowest score represents the least renewable energy potential according to the criteria of Resource Abundance, Mission Compatibility, annual estimated renewable energy potential, and energy consumption. The highest score represents the most potential based on the given criteria.

Table 6-2. Renewable energy potential metric results.

Installation	Renewable Energy Potential	Plausibility	Compatibility	Score
Fort Drum - Fort Drum	5.79	0.33	2.00	8.13
Fort Lewis	0.12	3.67	2.00	5.78
Fort Wainwright	1.01	1.67	2.00	4.68
Fort Bliss	0.06	2.00	2.00	4.06
Schofield Barracks Military Reservation	0.43	1.33	2.00	3.76
Fort Bragg	0.04	1.33	2.00	3.37
Fort Riley	0.80	0.33	2.00	3.14

6.3.4 Future improvements to the Renewable Energy metric

The *Renewable Energy* metric can be improved by using more scientific and established data in the analysis. For example the renewable energy potential values in the metric are sourced from survey data gathered at Army, Navy, and Air Force installations. This implies possible inconsistencies and subjectivity due to human error. Therefore, it is recommended that renewable energy potential data be taken from sources used by NREL to ascertain renewable energy potential numbers. It is also recommended that a simple equation be developed to evaluate only the renewable energy resources available. Additional analysis of costs, Mission Compatibility, and political regulations can be included using a data call that asks installation Energy or Public Works managers to evaluate these more specific details. The data call responses could be input into cost of base realignment (COBRA) and OSAF.

6.4 Infrastructure vulnerability

6.4.1 Justification for including vulnerabilities in metric

6.4.1.1 Hurricanes

Currently available data from climate change models suggest that the frequency and severity of hurricanes and ice storms will increase in the future. The number of Category 4 and 5 (the most severe) Atlantic hurricanes that occurred from 1970-2004 has doubled, coinciding with a period of increased ocean temperatures (Gibson et al. 2006). If current storm trends continue, structural repair costs will have a significant impact on utility and user costs; additionally if CO_2 levels in the atmosphere increase, hurricane wind velocities could increase by about 10% (Gibson et al. 2006).

6.4.1.2 Rainfall

Heavy rains from tropical rainstorms create major flooding in storm path areas and hundreds of miles from where the storm originally makes landfall. Following landfall, 5-10 in. of rain can fall. As a storm moves inland, the hurricane pressure and winds decrease and the storm is eventually downgraded to a tropical depression. However, the circulation, tropical moisture and geography of the landscape (topography) can contribute to large amounts of continuing rainfall (TWC 2014).

6.4.1.3 Wind

Wind is responsible for structural damage caused by hurricanes, which especially affects houses, trees, and power lines. Wind from fast moving and powerful storms remains high as storms travel inland (TWC 2014). Inland infrastructure along a storm path is therefore at continued risk. There is uncertainty with regard to the impact of climate change on hurricane intensity and frequency, however, the United States could have wind speed increases of up to 10%, which could contribute to a greater number of power system failures (Bjarnadottir et al. 2013).

6.4.1.4 Wildfires

Wildfires damage transmission poles (wooden poles are generally associated with lower voltage power lines/distribution lines), but a greater risk comes from smoke and particulate matter, which can ionize the air and create an electrical pathway away from the transmission lines, in turn shutting the lines down and causing power outages (Davis et al. 2014). In California, climate change is expected to increase the size and frequency of wildfires. Wind, accumulation of fuels for fire (combustible materials) and ignition sources (including lightning) are all factors that influence the frequency and impact of wildfires (Sathaye et al. 2011). Wildfires are also affected by moisture availability, which is influenced by temperature, precipitation, and snowpack, among other features affected by climate change (Sathaye et al. 2014). Since an increase in wildfires will impact the electric grid infrastructure, a spatial analysis of previous wildfire events must be done to evaluate infrastructure grid vulnerability and associated risk to Army installations (Figure 6-3).

6.4.1.5 SLR

SLR will impact electrical infrastructure located along the Gulf Coast, the Hampton Roads/Newport News region of Virginia, and power plants in coastal regions of California (Janetos 2006). Future sea level projections should be used to analyze the potential impacts on power plants and substations to determine risk to the overall availability of electricity connections to the grid.

Figure 6-3. Wildfire impact on low and high voltage transmission lines.

Image courtesy of B.O.R. Consulting
http://bor-consulting.weebly.com/wildfires---picture-gallery.html

6.4.2 Infrastructure vulnerability methodology

Climate change effects will increase the frequency and intensity of severe weather, which is the leading cause of power outages and fuel supply disruptions in the United States. The impact of climate change on storm systems is already apparent. Eight of the 10 most destructive hurricanes of all time occurred within the last 10 years (USDOE 2014b).

The increasing threat of droughts, wildfires, hurricanes, and SLR should be included in the stationing analysis to ensure that military training and quality of life are not negatively impacted due to power outages caused by severe weather.

The method for analysis of vulnerability to threats from wildfires, hurricanes and SLR on the national grid infrastructure (transmission lines, substations and power-generating facilities) is based on location proximity. The data used for this method are from the HSIP Gold and NOAA. HSIP Gold is a database for spatial data related to infrastructure; defense; security; and national hazard preparedness, protection, mitigation, response and recovery for communities. The database is assembled by the National Geospatial Intelligence Agency (NGA), in partnership with the Homeland Infrastructure Foundation-Level Data (HIFLD) Working Group for use by

Homeland Defense (HD), Homeland Security (HLS), and National Preparedness – Prevention, Protection, Mitigation, Response and Recovery (NP-PPMR&R) communities. It is a compilation of approximately 475 of the best available geospatially enabled baseline infrastructure data sets for all 18 Critical Infrastructure Key Resource Sectors assembled from Federal, state, local government, and private sector mission partners.

The methodology is as follows:

1. Gather and filter electric grid infrastructure data from HSIP Gold to those facilities and resources providing service to Army installations. Extract the transmission lines that support CONUS Army installations.
2. Gather and sort data from HSIP Gold and NOAA for wildfires, hurricanes, and SLR. Determine the installations where the locations of existing transmission lines have historically been impacted by wildfires or hurricanes using geographic information system (GIS) software.
3. Determine the natural hazard impacts on U.S. grid infrastructure supporting Army installations. Calculate a vulnerability score that signifies the level of impacts each hazard presents to the installation.
4. Average the wildfire and hurricane vulnerability scores to determine an overall infrastructure vulnerability score.
5. Reduce the transmission data to include only those lines connected to installations by performing a spatial intersection between transmission lines and Army installation boundaries.
6. Determine transmission line vulnerability by comparing wildfire occurrences and hurricane paths with the paths of transmission lines. Calculate the vulnerability of Army installation electricity infrastructure using the ratio of garrison transmission lines previously in the hazard path to transmission lines connected to the garrison. Calculating the ratio of transmission lines affected versus the total of all the lines powering the installation incorporates the redundancy[*] of electric power service to an installation. Multiply this ratio by the number of total hazard occurrences. This implements a representation of the frequency for which severe weather and hazard events occur around the installation.

[*] Here redundancy refers to the inclusion of transmission lines that are able to function in case other components of the grid (transmission lines) fail.

6.4.3 Infrastructure Vulnerability metric limitations

6.4.3.1 Proximity-based relationship

The methods to determine infrastructure vulnerability are based on location and proximity assumptions. That is to say, it is assumed that when a transmission line crosses an installation's boundary, it is supplying electricity to the garrison. Although this is most likely the case, the data do not confirm this or supply explicit evidence that it is true.

6.4.3.2 The dynamic nature of electricity

Electricity is provided on an interconnected network where supply must be balanced with demand 24 hours a day. Electricity flows in the path of least resistance, which makes it difficult to route the electricity from a specific source (generation station) to a specific load (installation) (Johnson, Miller, and Cruz-Montes 2011). This makes it difficult to discern the actual power-generating facility (or facilities) that supplies electricity to any given installation. Depending on the location, the electric utility provider can be determined, but the actual generation station may remain uncertain. That uncertainty limits the ability to assess vulnerability at the generating or resource level and the implication it would have for a particular Army installation.

6.4.4 Results of Infrastructure Vulnerability metric

6.4.4.1 Wildfire risk results

One hundred fifty-seven Army installations were analyzed to determine whether transmission lines powering those bases were in the same location as historic wildfires. Of the 157 installations analyzed, only 16 bases' transmission lines would have been impacted by historic wildfires and only three of the seven case study installations had been affected by wildfires (Table 6-3). These three installations experienced a total of 11 different wildfire events that occurred in the power line right-of-ways surrounding the bases.

Table 6-3 lists the results of the wildfire risk analysis. The installations are listed according to their relative vulnerability score. Fort Wainwright has the highest relative vulnerability with a score of 0.625. This score was derived by dividing the number of transmission lines affected by historic wildfires by the total number of transmission lines that power the base.

Table 6-3. Results of wildfire risk assessment.

Installation	Number of Transmission Lines Intersecting Base	Number of Transmission Lines Affected by Historic Wildfires	Share of Lines Affected by Wildfires	Number of Fires	Relative Vulnerability Score	Year(s) of Fire Occurrence
FORT BLISS	20	1	0.05	3	0.15	2009 2011
FORT BRAGG	6	0	0	0	0	N/A
FOR DRUM	4	0	0	0	0	N/A
FORT LEWIS	12	1	0.083	3	0.25	2004 2008 2010
FORT RILEY	2	0	0	0	0	N/A
FORT WAINWRIGHT	8	1	0.125	5	0.625	2001 2004 2006 2010
SCHOFIELD BARRACKS	0	0	0	0	0	N/A

The result or share of lines affected by wildfires is 0.125. Then multiply the share of lines affected by the total number of fires that have occurred in that location. This multiplication factor takes into account the frequency of occurrences. The final value, 0.625, is the relative wildfire vulnerability score. This score is just one component of the overall Infrastructure Vulnerability metric. The Year(s) column in the table is a reference to the years that those wildfires occurred. In some years, there was more than one wildfire event. For example, there were two wildfire events in 2001 that could have caused some efficiency loss or outages at Fort Wainwright.

6.4.4.2 Hurricane risk results

The same 157 Army installations analyzed for wildfire risk were also analyzed to assess spatial risk to hurricanes (Table 6-4). Of these 157 installations, 38 were found to be powered by transmission lines that cross paths with hurricane storm paths. Only two case study installations, Fort Bragg and Fort Bliss have historically had electrical infrastructure in potential conflict with hurricane storm paths. Fort Bragg has the highest relative vulnerability score due mainly to the fact that each of the six transmission lines that power the installation intersects with historic hurricane storm paths.

Table 6-4. Results of hurricane risk analysis.

Installation	Number of Transmission Lines Intersecting Base	Number of Transmission Lines Affected by Storms	Share of Lines in Historic Hurricane Paths	Number of Storm Events	Relative Vulnerability Score	Year(s) of Storm Occurrence
FORT BLISS	20	9	0.45	2	0.9	1970 2008
FORT BRAGG	6	6	1	3	3	1854 1913 1976
FOR DRUM	4	0	0	0	0	N/A
FORT LEWIS	12	0	0	0	0	N/A
FORT RILEY	2	0	0	0	0	N/A
FORT WAINWRIGHT	8	0	0	0	0	N/A
SCHOFIELD BARRACKS	0	0	0	0	0	N/A

6.4.4.3 SLR risk results

SLR differs from the previous two metrics. Transmission lines are not at significant risk due to SLR (however, flooding can negatively impact utility poles). Instead, SLR threatens power generation plants and voltage transformer substations. SLR analysis examined the relationship between projected sea levels in 2050 and 2070. The results determined that no Army installation is directly connected to electrical infrastructure that will be impaired by projected future SLR along coastal boundaries.

6.4.4.4 Overall infrastructure vulnerability results

Table 6-5 lists the final scores of the combined hurricane, wildfire, and SLR relative vulnerability analyses. No SLR category is included, however, because none of the case study installations are connected to substations or power-generating sources at risk to SLR. The SLR data were not included in the calculated averages listed in Table 6-5. To arrive at the final MVA score, simply subtract the average score from 10. This is done to match similar numbers of other MVA attributes (with values from 0-10). With the exception of Fort Bragg, these case studies result in relatively high MVA scores, meaning they are highly valuable or at relatively low vulnerability to national infrastructure power interruptions or failures.

Table 6-5. Infrastructure vulnerability score.

Installation	Relative Wildfire Vulnerability	Relative Hurricane Vulnerability	Average	MVA Score
FORT BLISS	0.15	0.9	0.525	9.475
FORT BRAGG	0	3	1.5	8.5
FORD DRUM	0	0	0	10
FORT LEWIS	0.25	0	0.125	9.875
FORT RILEY	0	0	0	10
FORT WAINWRIGHT	0.625	0	0.313	9.688
SCHOFIELD BARRACKS	0	0	0	10

6.4.4.5 Fort Bragg case study example

An example from the case study sites is Fort Bragg, which has a relative hurricane vulnerability score of 3. Fort Bragg had the highest relative vulnerability of the seven case study installations. There are six transmission lines that deliver power to Fort Bragg. According to the analysis, hurricane storm paths have crossed paths with all six transmission lines. Therefore the ratio of transmission lines impacted to total lines powering the base is 6:6 (value of 1). There have historically been three storms that affected these power lines. The value of the transmission line ratio is multiplied by the number of storms. The result of this final multiplication factor is the relative vulnerability score for hurricanes. In the case of Fort Bragg, the relative hurricane vulnerability score is 3.

6.4.5 Improvements to the Infrastructure Vulnerability metric

The *Infrastructure Vulnerability* metric attempts to combine the major forces of nature that pose threats to the distribution of and access to electricity, including wildfires, hurricanes, and flooding due to SLR. The proximity of national electrical infrastructure supporting Army facilities to these hazards is analyzed spatially. The results of the data are currently more qualitative than quantitative. It is recommended that vulnerability be calculated in terms of risk probability to provide more detailed results. Additionally, reanalyzing the spatial relationship and grid connections could be done at a larger spatial scale, for example, at the county level. This would cover a broader set of infrastructure and hazard data, resulting in a more regional approach. It is recommended to make this study broader to better address the highly integrated nature of the electrical distribution system.

7 Recommended Stationing Analysis Improvements

7.1 Use energy in Army stationing

The MVA run by CAA included energy in its *Environmental Elasticity* attribute, but its scope was limited to the review of kWh (electricity use) and therms (natural gas). The strength of the *Environmental Elasticity* attribute is that it combined water and energy and on-base population to determine a carrying capacity threshold.

7.2 Use water in Army stationing

In current Army stationing practices, water is incorporated in four parts of the analysis. This analysis presumes that water is a static resource and that the amount of water present today will continue to be present in the future. As previously illustrated, water availability is subject to the impacts of GCC and in the coming decades many areas will have less potable water. Furthermore, while the analysis of land available for various uses excludes land in flood plains from the total amount of available land, it does not address land at increased flood risk from SLR.

The *Water Quantity* MVA attribute examines whether there is enough water in a specified area to meet the installation's demands (CAA 2004a). This indicator views water as a cost of operation and as a static (unchanging) resource. This attribute fails to include external water pressures such as the possibility of drought, population growth in the surrounding area, or existing water withdrawal rates.

The *Environmental Elasticity* MVA attribute is defined as "the ability of an installation to absorb additional personnel based on the utility resource physical capacity constraints and resource costs at capacity thresholds" (CAA 2014). In the 2005 stationing analysis, the resources examined were:

- training land
- energy (electricity and natural gas)
- water and wastewater treatment and solid waste.

The *Environmental Elasticity* MVA attribute presumes per capita water use will remain constant and measures the ability of an installation to support additional growth. This attribute places a threshold capacity on water supply and treatment, which may be related to treatment plant size, distribution limits, and permit restrictions. The attribute presumes that current water use in regions can be sustained in the future.

The COBRA model includes recurring and one-time environmental and waste management costs. These numbers are determined from BOS statistics. Current BOS metrics related to water are Water Services, Waste Water Services, and Snow, Ice and Sand Removal (OACSIM 2013, p 13). The BOS costs provide an estimate as to the cost of operating an installation.

The *Buildable Acres* MVA attribute measures the capacity of an installation to add additional capacity through expanding the facilities on site based on the total number of buildable acres. The attribute specifically excludes land in the flood plain, where it is not safe to build (CAA 2014).

In BRAC 2005, Criterion 8 delineated 10 Environmental Resource Areas based on the categories required in National Environmental Policy Act (NEPA) assessments:

1. Air Quality
2. Cultural, Archeological, Tribal Resources
3. Dredging
4. Land Use Constraints, Sensitive Resource Areas
5. Marine Mammals, Marine Resources, Marine Sanctuaries
6. Noise
7. Threatened and Endangered Species, Critical Habitat
8. Waste Management
9. Water Resources
10. Wetlands.

All scenarios developed in the previous models were passed through Criterion 8 to assess the environmental impacts of a scenario. It was then used to assess the gaining (and losing) installations' environmental impacts. The Criterion 8 analysis focuses on the costs of environmental remediation—either to support additional capacity or to transfer the land into other Federal hands. Water costs in the 2005 Criterion 8 analysis were highly descriptive and focused on costs resulting from increased pollutant loads.

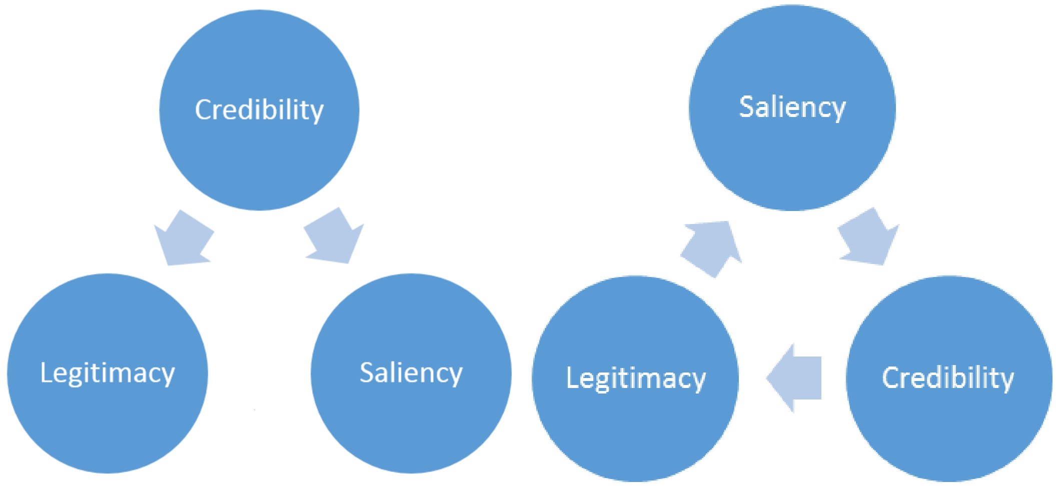
7.3 Adopt the knowledge-action paradigm

The recommendations provided in this report follow the saliency-credibility-legitimacy attribute triad to link knowledge and action to environmental decision making (Cash et al. 2003). Globally, connecting knowledge to action to meet human development needs, protect the environment, and respond to climate change has had limited success. Even when there is a clear political commitment, the limited success of projects has been attributed to gaps in the knowledge-action system, i.e., such gaps arise when decision makers do not get the information they desire, when tools are developed that do not answer the questions decision makers are asking, or when there is a lack of credibility for the process of knowledge creation (Cash et al. 2002). In sum, tools are generally not used because they lack credibility, saliency, or legitimacy.

Traditionally, translating knowledge into action has focused too heavily on credibility at the expense of legitimacy and saliency. Recent research demonstrates that, to be adopted, tools must have saliency and legitimacy (Cash et al. 2002; White et al. 2010). For example, a tool developed for local water managers that uses the best peer-reviewed climate change projections for stream flow may have a high level of credibility. However, the tool may not deal with a problem the water managers feel is an issue or is within their jurisdiction (saliency). Furthermore, the intended users of the tool may not view that the tool has legitimacy because it lacks saliency and it was clear that their views were not incorporated. Hoping to bridge the knowledge-action gap, this work is based on the saliency-credibility-legitimacy attribute triad (Figure 7-1).

Throughout the process of developing these recommendations, researchers have built a relationship with CAA (the client). Regular bi-weekly phone contacts were maintained to clarity issues as they arose and to solicit feedback on the process. It is hoped that this direct engagement will give this work greater relevance to the client's needs.

Figure 7-1. The knowledge-action paradigm has historically placed an emphasis on credibility (left); this work recognizes the interconnected nature of saliency, credibility, and legitimacy.



The terms used in Figure 7-1 are defined as follows:

- *Credibility* refers to the scientific adequacy of the technical arguments and evidence. The rigor of the data and of the assumptions made in analysis must be addressed for the tools and data developed to be accepted by the scientific community and practitioners. To ensure the creditability of their work, CAA insists that it fit within the SMART criteria (Specific, Measurable, Attainable, Realistic, and Timely). The SMART criteria ensure that the data and analysis are reproducible. The credibility of the science underlying this research has further been ensured by conducting an extensive literature review, recognizing limitations in this research, and using the best data sources available.
- *Saliency* deals with the relevance of the tools developed to the needs of decision makers and the problem being addressed. These recommendations and tools demonstrate saliency by working within the existing frameworks developed by CAA.
- *Legitimacy* refers to the perception that stakeholders believe that their views have been incorporated. These recommendations are based on bi-weekly conversations with CAA, feedback received when CAA leaders visited CERL in May 2014, and invaluable feedback CAA provided on working drafts. As the agency in charge of Army stationing practices, CAA has been an active member of the creation of these recommendations and initial feedback indicates that they find these recommendations useful.

7.4 Improve military data call questions

The questions in the Military Data Call, which are the questions sent to installations by the Office of the Secretary of Defense and which populate the BRAC models, are lacking in how they deal with water. The questions lack specificity in asking about the sources of water, water use, and water recycling. The addition of one more question and improving the language used in the current water use questions will improve the quality of the data, thereby improving the quality of the analysis results.

Question 826 in the 2004 Military Data Call asked:

> What was the average daily water use in Millions of Gallons per day (MGD) for FY01, FY02 and FY03? Combine usage of Potable and Non-Potable and report as Total Average Daily Use.

This question currently does not specify if the water is recycled. Some installations that recycle water may receive a lower score as it indicates that they are using a high percentage of their available water, while in practice they are drawing only a percentage of the water they consume. In Colorado recycled water counts toward the water that is taken from water rights, as it is not returned immediately to the watershed. As a result, understanding how the water is used is necessary to determine how much of the available water is actually used.

It is recommended that the following questions be added to the Military Data Call:

> Of the total water that the installation has rights to, how much of the water was considered unsafe for drinking?
> If your installation recycles water, what was the highest average daily water use in MGD including: (a) the recycled water and (b) water directly from the source.

Understanding the source of an installation's water is crucial to ensuring that an installation has water to carry out its mission.

7.5 Include energy resources in the Environmental Elasticity MVA Attribute

Adding the renewable energy metric and Infrastructure Vulnerability metric to the *Environmental Elasticity* attribute would make for a much stronger MVA attribute. For example, Fort Bliss had an overall vulnerability score of 9.475. It was ranked as the second most vulnerable of the seven case study installations. However as Fort Bliss adds alternative energy technologies to its portfolio, it will become less dependent on the national infrastructure and those vulnerabilities will be reduced. Therefore, making improvements to each and developing a way to combine these two metrics would make for a stronger metric.

7.5.1 Renewable energy metric

The *Renewable Energy* metric is intended to be incorporated in the *Environmental Elasticity* attribute of the MVA process. The *Renewable Energy* metric takes a holistic approach to analyze renewable energy potential by incorporating site-specific political, economic, environmental, and training realities. These characteristics include state incentives and regulations impacting renewable energy. This is an important metric for an Army installation as it indicates the status of an installation's energy security and reduced vulnerability to disruptions to the national energy grid systems. Inclusion of the renewable energy metric in the analysis will better equip the process to assess installations that can meet Army mandates for renewable energy use and that can reduce vulnerability from reliance on outside power sources.

7.5.2 Infrastructure Vulnerability metric

Infrastructure vulnerability should be added to the *Environmental Elasticity* MVA attribute. However it could be redesigned as an OSAF constraint as well. The current methods for infrastructure vulnerability analysis are GIS-intensive. It is possible to perform an overall analysis of infrastructure vulnerability and threats to all U.S. Army installations and then provide results to CAA. Repeating the methods used to determine national grid infrastructure vulnerability is feasible for CAA if the staff has GIS application knowledge. Although the methods can be repeated, it is recommended that the infrastructure analysis be improved.

7.5.3 Building energy consumption and costs

Further research on climate change impacts on total building energy consumption, EUI, and costs will continue at the Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). This research will use building type and area (square feet) data in a building energy modeling software tool developed by engineers at CERL known as Net Zero Planner (NZP). NZP is an optimization tool that uses building, energy use, and weather data files for strategic planning. Its use is recommended to incorporate climate change scenarios' impact on energy consumption at the installation level. Building type and area data will be derived from DoD Real Property Assets Database. Weather files are from the Typical Meteorological Year 3 (TMY3) database.

7.6 Incorporate land lost from Sea Level Rise into stationing analysis

7.6.1 Add SLR and flooding to the *Buildable Acres* MVA attribute

The *Buildable Acres* MVA attribute assesses the ability of an installation to support additional forces by expanding the facilities on site. The attribute is the total of all buildable acreage on site, excluding training land. The *Buildable Acres* MVA attribute updated on 12 February 2014 for CONUS Stationing resulting from the drawdown in force excludes lands with constrained uses, such as flood plains, contaminated sites, and endangered species habitats (CAA 2014).

As the "Land Lost to SLR" results have demonstrated, 10 coastal installations may lose land from SLR. As a result of storm surge and SLR, the amount of buildable acres on an installation will be affected. Marking areas where increased sea level inundation is expected as constrained use areas will be a more accurate reflection of future events.

7.6.2 Add land lost from SLR to test range capacity

The *Test Range Capacity* MVA attribute is the "combination of total square miles and the cubic airspace of test range facilities at an installation that can support test and evaluation" (CAA 2004c). The attribute is the amount of land in square miles defined as Military Operational Areas.

As demonstrated, SLR will reduce the amount of land available for training. Future stationing analyses should exclude areas expected to be inundated from the test ranges.

7.6.3 Include shifts to water consumption stress vulnerability in the *Environmental Elasticity* MVA attribute

The *Environmental Elasticity* MVA attribute quantifies the ability of an installation to economically absorb additional forces. The attribute includes capacity thresholds for energy, water, and wastewater. For water supply and treatment, threshold capacity restrictions may be due to treatment plant size, distribution limits, or permit restrictions. These thresholds are economically based, and indicate the level at which significant additional infrastructure would have to be built to accommodate additional users.

The Future Water Consumption Stress Index should be used to establish an additional threshold capacity, which is the number of Soldiers that can be added to an installation before the water consumption stress score for the region shifts to extreme stress. Installations located in areas with extreme stress will be treated as lacking capacity to gain additional Soldiers.

7.7 Reframe the *Critical Infrastructure* MVA attribute

The *Critical Infrastructure* MVA attribute measures the number of Critical Infrastructure nodes located within 150 miles of the installation. These nodes are defined as power-generating reactors, major dams, Federal Reserve banks, ports, 25 most dangerous chemical plants, and refineries. This measure indicates an installation's potential capability to support consequence management and Homeland Defense missions, including military assistance for civil disturbance, natural disasters, Chemical, Biological, Radiological, Nuclear and Enhanced Conventional Weapons (CBRN&E) accidents, terrorist incidents, and military assistance to civil law enforcement agencies (CAA 2004b).

As demonstrated through this analysis of infrastructure at risk of flooding from large storm events and SLR, community infrastructure may be affected in the coming decades from climate change. Therefore, the *Critical Infrastructure* MVA attribute should be expanded to include the amount

of community infrastructure at risk of destruction from flood events. However, a nested geographical approach is necessary:

- If an installation is located in an area (40 miles) with a high amount of infrastructure at risk of SLR, then it may not be an ideal location for an installation, as that may affect installation capacity.
- However, if an installation is still located in proximity (150 miles), but not directly located in an at-risk area it will be able to provide support during contingencies.

7.8 Expand the time line of analyses

Currently stationing analyses are conducted on a 20-year NPV cost horizon. Costs incurred from restationing, especially infrastructure costs, are expected to be amortized within a 20-year period. Current stationing analysis leverages past military construction investments, meaning that installations may be favored because of new infrastructure that was developed in previous stationing efforts (Bott 2013).

As this report has demonstrated, the Army will be affected by climate change. Those effects, however, may not fully materialize on a 20-year horizon. As leveraging past military construction/investments is a consideration in stationing decisions (albeit outside of the MVA model), stationing decisions made now to favor certain sites will have consequences in the future. By expanding the timeline of analysis to 2050, the long term value of an installation can be better captured.

7.9 Improve the use of Criterion 8 in cost estimating

Every scenario is judged based on all eight criteria although Criterion 5 (Cost) is certainly an especially important consideration. In BRAC 2005, Criterion 8 delineated 10 Environmental Resource Areas, based on the categories required in NEPA assessments: (1) Air Quality; (2) Cultural, Archeological, Tribal Resources; (3) Dredging; (4) Land Use Constraints, (5) Sensitive Resource Areas; (6) Marine Mammals, (7) Marine Resources, (8) Marine Sanctuaries; (9) Noise; (10) Threatened and Endangered Species, (11) Critical Habitat; (12) Waste Management; (13) Water Resources; and (14) Wetlands. All scenarios developed in the previous models were passed through Criterion 8 to assess the environmental impacts of a scenario. It was then used to assess the gaining installations' environmental impacts.

7.9.1 Integrate science in Criterion 8 analysis

The current Criterion 8 analysis provides the cost to the U.S. Army to execute stationing scenarios with regards to the environmental cost. The analysis considers each of the 10 resource areas for each scenario by providing a summary of the responses to military data call questions. Costs are then identified to remedy these environmental issues.

Ensuring accuracy in cost estimates will help ensure that stationing decisions are made in the best interest of the U.S. Army. Current practices rely on a highly descriptive approach, and would benefit from limited quantification of results. For example, in the 2005 report the following was written about Aberdeen Proving Ground: “water quality is impaired by pollutant loadings. Significant mitigation measures to limit releases may be required ...” The analysis failed to identify the pollutants in the waterways, to state whether the installation was contributing to those high levels, or to indicate if the installation currently had plans in place to reduce TMDL.

The quality of results of the analysis would improve through quantification. The Water Quality metric could be leveraged to quantify the extent of impaired water.

7.9.2 Improve cost estimations

The total cost of environmental remediation drives the outcomes of the Criterion 8 scenarios. While the least expensive option will not always be selected, cost is certainly important, but not the only factor, considered. The cost analysis currently lacks substance. There is a need to improve cost estimation to provide a better estimate of total costs that influence the decision. As noted above, Aberdeen Proving Ground research found that the “water quality is impaired by pollutant loadings. Significant mitigation measures to limit releases may be required.” However, the analysis provided no information on what type of water quality issues the installation had, or the extent of TMDL within the region. Furthermore, the cost estimate for fixing the issue at the base was provided in a range of $100k - $3M, yet the total cost of environmental work at Aberdeen Proving Ground was $1.5 million (Crabtree 2005).

At Fort Bliss a “significant impact” on water resources was identified with an increase in 20,000 active-duty personnel with an additional increase of

30,000 persons, including families and support services personnel. The analysis noted that this would require upgrading water and wastewater systems as well as purchasing potable water resources. Despite the significant cost this could impose, it was not included in the "impact of costs" analysis or in the final cost analysis.

7.10 Make Army Net Zero installations an OSAF constraint

The OSAF prescribes an optimal stationing plan for forces. The model uses existing start locations for forces, the set of possible installations that they can be sent to, the amount of available funds, and installation restrictions such as "ensure Apache helicopter training is restricted to Forts Bliss, Carson, and/or Hood." One of the factors that can be considered in OSAF is "other," which includes special considerations for installations. If these special considerations are added as constraints, OSAF can determine the cost of imposing them. These constraints are documented and stated explicitly, allowing stakeholders transparency to the assumptions in the analysis (Dell et al. 2014).

Net Zero Army pilot installations should be made a constraint in the OSAF model. The Army is piloting five installations to be Net Zero Energy, five installations to be Net Zero Water, five installations to be Net Zero Waste, and one installation to be Net Zero Energy/Water/Waste by 2020. The Net Zero program vision is to appropriately manage natural resources so that installations will consume only as much energy or water as they produce and eliminate the disposal of solid waste in landfills. DoD is investing significant time and monetary resources into these installations to make them "centers of environmental and energy excellence" (Foster 2011).

8 Conclusions and Recommendations

8.1 Conclusions

With respect to water and energy support to Army installations, it is anticipated that major climate change impacts will manifest as possible temperature and precipitation changes that will have secondary effects related to water, including:

- rising sea levels
- increased snow melt and inability of snow and ice packs to replenish
- increased frequency and severity of droughts in some locations simultaneous with increased precipitation in other areas
- increased frequency and severity of storm events
- decreased aquifer and surface reservoir levels
- increased risk of flooding, with associated damage to infrastructure and the environment
- increased risk of wildfires, impacting training lands, utility right-of-ways, etc.

8.2 Recommendations

It is recommended that the existing MVA attributes discussed in the following sections be augmented and restored to the stationing decision analysis process.

8.2.1 Water Quantity

Analysis of the *Water Quantity* MVA attribute to include two new metrics—water consumption stress and water quantity— will change the rankings of installations. For example, it was found that the MV of JBLM increased significantly because the region has plentiful regional water assets, but the ranks of Fort Bliss and Fort Drum dropped slightly because of regional water stress. This analysis demonstrates the value of updating the *Water Quantity* MVA attribute, to include:

- *Water Consumption Stress*, which identifies the regional water stress of CONUS installations. This analysis identifies areas of existing water stress, demonstrating areas where an installation may compete with the surrounding region for water.

- *Water Quantity*, which measures the amount of water on and surrounding the installation that is considered polluted (impaired) under Section 303(d) of the CWA. The proposed updated *Water Quantity* MVA attribute includes impaired waterways as an indicator of degraded water quality.

8.2.2 Environmental Elasticity

It is recommended that the *Environmental Elasticity* MVA attribute be updated to include three new factors: — renewable energy, infrastructure vulnerability, and water stress shifts.

- *Renewable Energy*, which measures the renewable energy capacity of installations.
- *Infrastructure Vulnerability*, which measures the vulnerability of installations to energy infrastructure destruction through climate-related events such as wildfires, hurricanes, sea level rise, and flooding.
- *Water Stress Shifts*, which measures how many additional people a region can support before the region shifts to "high" water stress.

8.2.3 SLR

SLR will affect the U.S. Army. The locations of seven case study sites indicate that the effects of SLR may be minimal, but a national screening demonstrates that more sites will be affected. Further work is needed to screen installations and the effects of SLR. It is recommended that the following be updated to include the possible impact of SLR:

- *Test Range Capacity* MVA attribute. The Test Range Capacity MVA attribute is the "combination of total square miles and the cubic airspace of test range facilities at an installation that can support test and evaluation" (CAA 2004c). It is recommended that land expected to be inundated with sea water be excluded from test range capacity.
- *Buildable Acres* MVA attribute. The Buildable Acres MVA attribute assesses the ability of an installation to gain additional force capacity by expanding the facilities on site. It is recommended that land expected to be inundated with sea water be excluded from the amount of buildable acres.
- *Critical Infrastructure* MVA attribute. While it is possible for climate change to impact the *Urban Sprawl* and *Critical Infrastructure* MVA attributes, it is not recommended that the effect on these attributes be further considered.

Acronyms and Abbreviations

Term	Definition
AEC	Army Environmental Command
AEMR	Annual Energy Management Report
AEWRS	Army Energy and Water Reporting System
AFB	Air Force Base
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASIP	Army Stationing and Installation Plan
AEWRS	Army Water and Energy Reporting System
BMP	Best Management Practice
BOS	Base Operating Support
BPA	Bonneville Power Administration
BRAC	Base Realignment and Closure
BTU	British Thermal Unit
CAA	Center for Army Analysis
CBRN&E	Chemical, Biological, Radiological, Nuclear and Enhanced Conventional Weapons
CCSP	U.S. Climate Change Science Program
CEERD	US Army Corps of Engineers, Engineer Research and Development Center
CERL	Construction Engineering Research Laboratory
CESL	Comprehensive Evaluation of Projects with Respect to Sea Level Change
CNA	Center for Naval Analyses
COA	Course of Action
COBRA	Cost of Base Realignment Analysis
CONUS	Continental United States
CSO	Combined Sewer Overflow
CWA	Clean Water Act
DCIP	Defense Critical Infrastructure Program
DO	Dissolved Oxygen
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DPW	Directorate of Public Works
DSCA	Defense Support of Civil Authorities
EIA	Energy Information Administration
EMM	Electricity Market Module
EO	Executive Order
EPWU	El Paso Water Utilities
ERDC	Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory

Term	Definition
ESG	Energy Security Goal
EUI	Energy Use Intensity
FC	Fecal Coliform
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FY	Fiscal Year
GAO	Government Accountability Office
GCC	Global Climate Change
GIS	Geographic Information System
GMSL	Global Mean Sea Level
GSHP	Ground Source Heat Pump
HD	Homeland Defense
HIFLD	Homeland Infrastructure Foundation-Level Data (Working Group)
HLS	Homeland Security
HSA-JCSG	Headquarters and Support Activities Joint Cross-Service Group
HSIP	Homeland Security Infrastructure Program
HUC	Hydrologic Unit Code
ICLUS	Integrated Climate and Land Use Scenarios
ISR-NI	Installation Status Report - Natural Infrastructure
ISSN	International Standard Serial Number
JAG	Judge Advocate General
JBLM	Joint Base Lewis-McChord
KML	Keyhole Markup Language
KSG	(Harvard University, John F.) Kennedy School of Government
LEAM	Land-use Evolution and impact Assessment Model
LLC	Limited Liability Company
MGD	Millions of Gallons per Day
MILDEP	Military Department
MMBTU	Million BTU
MMBTU/KSF	Million BTU per Thousand Square Feet
MV	Military Value
MVA	Military Value Analysis
N/A	Not Applicable
NAICS	North American Industrial Classification System
NCA	National Climate Assessment
NDBC	National Data Buoy Center
NEPA	National Environmental Policy Act
NERC	North American Electricity Reliability Council
NGA	National Geospatial Intelligence Agency
NHD	National Hydrography Dataset

Term	Definition
NHI	National Highway Institute
NOAA	National Oceanic and Atmospheric Administration
NP-PPMR&R	National Preparedness – Prevention, Protection, Mitigation, Response and Recovery
NPS	Nonpoint Source
NPV	Net Present Value
NRC	National Research Council
NREL	National Renewable Energy Laboratory
NSN	National Supply Number
NZP	Net Zero Planner
OACSIM	Office of the Assistant Chief of Staff for Installation Management
OAR	Office of Oceanic and Atmospheric Research
ODUSD I&E	Office of the Secretary of Defense, Installations and Environment
OMB	Office of Management and Budget
OSAF	Optimal Stationing of Army Forces
OSAF/MVA	Optimal Stationing of Army Forces/Military Value Analysis
PC	Personal Computer
PNNL	Pacific Northwest National Laboratory
POC	Point of Contact
PPA	Power Purchase Agreement
P-PET	Available Precipitation
PV	PhotoVoltaic
SAR	Same As Report
SF	Standard Form
SIRRA	Sustainable Installations Regional Resource Assessment
SLR	Sea Level Rise
SMART	Specific, Measurable, Attainable, Realistic, Timely
SME	Subject Matter Expert
TMDL	Total Maximum Daily Load
TR	Technical Report
TWC	The Weather Channel
USA	United States of America
USACE	U.S. Army Corps of Engineers
USAG	U.S. Army Garrison
USEIA	U.S. Energy Information Administration
USEPA	U.S. Environmental Protection Agency
USGCRP	U.S. Global Change Research Program
USGS	US Geological Survey
USSOCOM	U.S. Special Operations Command
WFO	(National Weather Service) Weather Forecast Office

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Appendix A: Climate Change Supporting Documentation

The data in Table A-1 are adapted from the High-Level Climate Change Vulnerability Assessment (Hayden et al. 2013) and demonstrate the relationship of climate phenomena to Army installation mission requirements.

Table A-1. Relationship of climate phenomena to Army installation mission requirements.

Climate Change Phenomena	Potential Impacts	Potential Mission Impacts
Rising Temperatures	Increased number of cumulative days with temperatures >95 °F; melting permafrost; increased incidences of heat stress; changes in incidence/distribution of vector- borne diseases; vegetation transition (species and biome shifts); wildfire risk, soil warming; electrical grid stress; degradation of equipment performance	Shift in viable test/training mission; potential loss of cold weather training venues; reduced Soldier activity levels; reduced military vehicle access; reduced airlift capacity; reduced live-fire training; change in operational parameters for weapons and equipment development and testing; increased maintenance costs; increased energy costs for building and industrial base operations
Increasing drought frequency	Increases in extent and duration of droughts; increased wildfire risk; altered burn regimes; loss of vegetative cover; impacted soil function and resilience (desertification); soil loss, increased dust; impacts to air quality; infrastructure damage; water supply constraints, impacted groundwater and surface water quality; protected species stress	Reduced land carrying capacity for vehicle maneuvers; increased maintenance costs for roads, runways, and utilities; limits on low-level rotary wing flight operations; increased regulatory constraints on training land access; reduced live-fire training; reduced water availability and greater competition for limited water resources
Increasing storm frequency and intensity	Increases of extreme precipitation events; increased flooding; water quality issues; soil and vegetation loss; impacts to soil function and carbon/nutrient cycling; transportation infrastructure damage	Impacts to Soldier safety; reduced access to military water crossings and river operations; reduced off-road maneuver capacity; increased maintenance costs; increased flood control/erosion prevention measures; increased transportation infrastructure damage
Rising sea levels, storm surge expansion onto land	Loss of coastal land; damage to physical infrastructure (roads, targets, ranges) and protected ecosystem resources; land subsidence; saltwater intrusion	Degradation or loss of coastal infrastructure; increased infrastructure damage and associated reinforcement and repair costs; impacts to littoral and shore training; increased regulatory constraints on training land access; impacts on supply chain from potential shipping interruptions
Altered carbon cycles, sequestration and release	Increased stress on protected species; more listed species; spread of invasive species; land management impacts; competing non-military land use; reduced soil function	Reduced training land access; reduced training carrying capacity

Appendix B: Supporting Tables

Table B-1. Types of community infrastructure located within 40 miles of an installation that are at risk of destruction from a flood event.

Infrastructure Category	SLR 2050		SLR 2070		100-year Flood Zone		500-year Flood Zone	
	# of Assets	% Total*	# of Assets	% Total	# of Assets	% Total	# of Assets	% Total
Places of Worship	293	7.9%	315	8.0%	4,350	9%	4,226	10%
Blood and Organ Banks	26	0.7%	26	0.7%	207	0%	169	0%
Colleges and Universities	67	1.8%	70	1.8%	658	1%	719	2%
Day Care Centers	824	22.2%	880	22.4%	11,567	25%	11,500	27%
Electricity Generation	28	0.8%	28	0.7%	116	0%	29	0%
Emergency Medical Service	441	11.9%	478	12.2%	5,729	12%	3,891	9%
Fire Stations	159	4.3%	174	4.4%	2,555	5%	1,243	3%
Hospitals	52	1.4%	57	1.5%	534	1%	482	1%
Law Enforcement	326	8.8%	345	8.8%	3,391	7%	2,510	6%
Libraries	467	12.6%	489	12.5%	4,262	9%	3,441	8%
Nursing Homes	562	15.1%	563	14.3%	5,179	11%	5,481	13%
Public Schools	398	10.7%	429	10.9%	7,603	16%	7,833	19%
Solid Waste Landfills	29	0.8%	30	0.8%	251	1%	114	0%
Urgent Care Facilities	29	0.8%	30	0.8%	536	1%	552	1%
Veterans Health Administration	9	0.2%	10	0.3%	111	0%	97	0%
# of Assets: Number of infrastructure in category within 300 ft of scenario								
*% Total indicates the percentage the category accounts for of all infrastructure at risk in the given scenario								

Table B-2. Land on coastal installations at risk of flood inundation as a result of SLR in 2050 and 2070

Installation Name	Installation Type	Installation Area	2050 SLR		2070 SLR	
			Acres Lost	% Lost	Acres Lost	% Lost
Aberdeen Proving Ground	Proving Ground	67,428	330	0.5%	330	0.5%
Fort Belvoir	Support Installation	7,892	101	1.3%	156	2.0%
Fort Hamilton	Support Installation	147	0.1	0.1%	0.1	0.1%
Fort McNair	Professional Education	105	0.4	0.4%	1	0.8%
Fort Shafter	Support Installation	584	0.0	0.0%	2	0.3%
Fort Stewart	Maneuver Installation	266,543	508	0.2%	508	0.2%
Joint Base Langley-Eustis	Training School	10,216	693	6.8%	1,407	13.8%
JBLM	Maneuver Installation	87,362	2	0.0%	2	0.0%
Military Ocean Terminal Sunny Point	Support Installation	11,303	267	2.4%	267	2.4%
West Point Military Reservation	Professional Education	15,120	3	0.0%	30	0.2%

Table B-3. Water stress scores for CONUS installations.

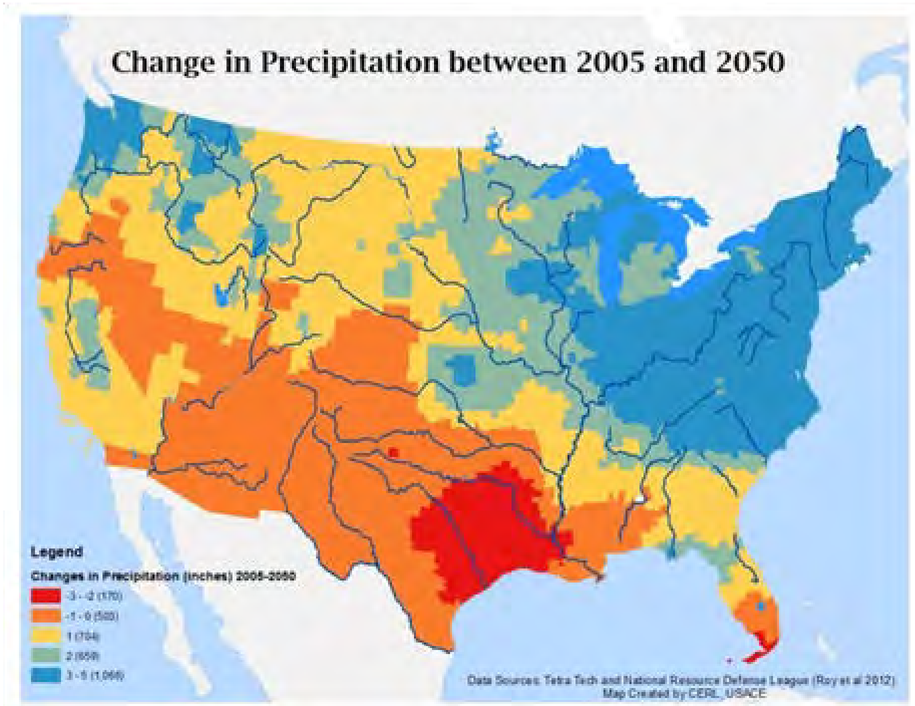
Installation Name	Stress Score 2005	Stress Category 2005	Stress Score ’50	Stress Category ’50
Aberdeen Proving Ground	2	Moderate	2	Moderate
Adelphi Laboratory Center	3	High	3	High
Anniston Army Depot	0	Low	3	High
Blue Grass Army Depot	0	Low	0	Low
Carlisle Barracks	0	Low	0	Low
Corpus Christi Army Depot	4	High	4	High
Crane Army Ammunition Activity	2	Moderate	3	High
Detroit Arsenal	1	Moderate	2	Moderate
Dugway Proving Ground	5	Extreme	5	Extreme
Fort A P Hill	1	Moderate	1	Moderate
Fort Belvoir	1	Moderate	1	Moderate
Fort Benning	1	Moderate	2	Moderate
Fort Bliss	5	Extreme	6	Extreme
Fort Bragg	1	Moderate	1	Moderate
Fort Campbell	0	Low	1	Moderate
Fort Carson	3	High	3	High
Fort Detrick	1	Moderate	1	Moderate
Fort Drum	1	Moderate	2	Moderate
Fort Gordon	0	Low	1	Moderate
Fort Hamilton	2	Moderate	2	Moderate
Fort Hood	2	Moderate	4	High
Fort Huachuca	6	Extreme	6	Extreme
Fort Jackson	2	Moderate	2	Moderate
Fort Knox	2	Moderate	2	Moderate
Fort Leavenworth	2	Moderate	3	High
Fort Lee	1	Moderate	2	Moderate
Fort Leonard Wood	1	Moderate	2	Moderate
Fort McNair	0	Low	1	Moderate
Fort Meade	4	High	5	Extreme
Fort Polk	2	Moderate	3	High
Fort Riley	2	Moderate	3	High
Fort Rucker	2	Moderate	2	Moderate
Fort Sam Houston	5	Extreme	5	Extreme
Fort Sill	1	Moderate	3	High
Fort Stewart	2	Moderate	2	Moderate
Hawthorne Army Depot	4	High	5	Extreme
Holston Army Ammunition Plant	2	Moderate	3	High

Installation Name	Stress Score 2005	Stress Category 2005	Stress Score '50	Stress Category '50
Iowa Army Ammunition Plant	1	Moderate	3	High
Judge Advocate General (JAG) Legal Center and School	0	Low	0	Low
Joint Base Langley-Eustis	1	Moderate	1	Moderate
JBLM	3	High	2	Moderate
Joint Base McGuire-Dix	3	High	3	High
Joint System Manufacturing Center Lima	1	Moderate	1	Moderate
Lake City Army Ammunition Plant	3	High	4	High
Letterkenny Army Depot	2	Moderate	2	Moderate
Longhorn Army Ammunition Plant	1	Moderate	2	Moderate
McAlester Army Ammunition Plant	1	Moderate	2	Moderate
Milan Army Ammunition Plant	2	Moderate	3	High
Military Ocean Terminal Concord	4	High	4	High
Military Ocean Terminal Sunny Point	3	High	3	High
National Training Center And Fort Irwin	5	Extreme	5	Extreme
Picatinny Arsenal	2	Moderate	2	Moderate
Pine Bluff Arsenal	5	Extreme	6	Extreme
Presidio Of Monterey	6	Extreme	6	Extreme
Pueblo Chemical Depot	3	High	4	High
Radford Army Ammunition Plant	0	Low	0	Low
Red River Army Depot	1	Moderate	2	Moderate
Redstone Arsenal	1	Moderate	2	Moderate
Rock Island Arsenal	4	High	4	High
Scranton Army Ammunition Plant	0	Low	0	Low
Sierra Army Depot	4	High	4	High
Soldier Systems Center Natick	3	High	3	High
Tobyhanna Army Depot	0	Low	0	Low
Tooele Army Depot	5	Extreme	5	Extreme
U.S. Army Adelphi Laboratory Center	3	High	3	High
Walter Reed Army Medical Center	0	Low	1	Moderate
Watervliet Arsenal	0	Low	0	Low
West Point Military Reservation	2	Moderate	3	High
White Sands Missile Range	4	High	3	High
Yuma Proving Ground	4	High	4	High

Table B-4. Community infrastructure within 40 miles of installation at risk of SLR.

Installation Name	State	# Assets 2050	# Assets 2070
Aberdeen Proving Ground	MD	81	87
Adelphi Laboratory Center	MD	39	40
Corpus Christi Army Depot	TX	2	3
Fort A P Hill	VA	12	14
Fort Belvoir	VA	25	27
Fort Hamilton	NY	361	422
Fort Lee	VA	5	5
Fort McNair	DC	38	39
Fort Meade	MD	43	44
Fort Shafter	HI	32	35
Fort Stewart	GA	53	53
Joint Base Langley-Eustis	VA	141	174
JBLM	WA	48	48
Joint Base McGuire-Dix	NJ	186	258
Joint Base Myer-Henderson Hall	VA	36	37
Military Ocean Terminal Concord	CA	309	309
Military Ocean Terminal Sunny Point	NC	20	21
Picatinny Arsenal	NJ	258	306
Presidio Of Monterey	CA	7	7
Radford Army Ammunition Plant	VA	4	5
Schofield Barracks	HI	32	35
Soldier Systems Center Natick	MA	244	244
Tripler Army Medical Center	HI	32	35
U.S. Army Adelphi Laboratory Center	MD	39	40
Walter Reed Army Medical Center	MD	38	39
Watervliet Arsenal	NY	7	7
West Point Military Reservation	NY	200	236
# of Assets: Number of infrastructure in category within 300 ft of scenario			

Figure B-1. Expected precipitation changes between 2005 and 2050; the southwestern United States will have reductions in precipitation while the northeastern United States will experience increased precipitation.



Appendix C: Documentation of Regional Water Consumption Stress Calculation

C.1 Proposed *Water Quantity* MVA attribute

1. **Definition:** The availability of water resources to an installation and its locational vulnerability and susceptibility to water shortages.
2. **Purpose:** Measures the availability of water resources within the geographic region of the installation as well as risk of water shortages. The availability of water, including surface water, groundwater and purchased water, as well as current regional pressures critical to understanding the degree of sustainability of natural resources. Sufficient water may not be available to allow for expansion of missions at the installation regardless of the physical throughput of the water treatment plant.
3. **Source/ Point of Contact (POC):** Installation Military Value Data Call, DoD Questions #825 and #826, Rad 303 (d) dataset from the USEPA, and metadata from Roy et al.
4. **Methodology and Background:**
   a. Water sources may vary among installations; therefore, report the total available from all sources. Available sources may include: (1) surface water runoff from contiguous watersheds, (2) surface water runoff from non-contiguous watershed, and (3) principal or local aquifers. Often these measures give safe yields from existing watersheds and aquifers. Typical units of measure are thousands of acre-feet.
   b. Increased water use by humans not only reduces the amount of water available for industrial and agricultural development, but has a profound effect on aquatic ecosystems and their dependent species. Human activities have severely affected the condition of freshwater ecosystems, to a point where many freshwater species are facing rapid population declines or extinction.
   c. Climate change is already reducing the availability of potable water and, with increasing droughts throughout the southern United States, the amount of water will decrease even more. Understanding the areas that are currently at risk of water shortages is crucial.
5. **Equations:**
   a. Calculate Water Availability for each installation using:

$$\Gamma = \sum_{i=1}^{n} w_i - \left(Q_{avg} \times \frac{1{,}000{,}000 \cdot Gal}{1 \cdot MG} \times \frac{1 \cdot ft^3}{7.481 \cdot Gal} \times \frac{1 \cdot Acre \cdot foot}{43{,}560 \cdot ft^3} \times \frac{365 \cdot days}{1 \cdot year} \right) \quad (8\text{-}1)$$

where:

Γ = Total water availability is the amount of additional water that the installation is entitled, compared to current average consumption, over a given year. It is calculated from the difference between all available resources and the average water use.

w_i = Water Allocation. Sum of the quantity of water available from each water source (n = number of sources) that the installation is entitled, for a given year. TABS calculates the total available water.

Q_{avg} = is the highest reported average daily use value (MGD) over the past 3 years.

Standardize the results to standardized Z-scores where the mean is equal to 0 and the standard deviation is one.

6. **Calculate the Water Stress Index:**
   a. Use the Water Stress Index to identify counties that had water stress in 2005 (Roy et al. 2012).
   b. Use the Sustainable Installations Regional Resource Assessment (SIRRA) methodology to compute scores for installations if they are in multiple counties.
   c. Standardize the results to standardized Z-scores where the mean is equal to 0 and the standard deviation is one.
7. **Calculate the Water Quality Index Using:**

$$4A + 2B + 3C + D \quad (8\text{-}2)$$

where:

A = Acres of impaired water on an installation
B = Percentage of the installation's land covered by impaired water
C = Acres of impaired water within a half mile of the installation.
D = Percentage of the acres within a half mile of the installation covered by impaired waters.

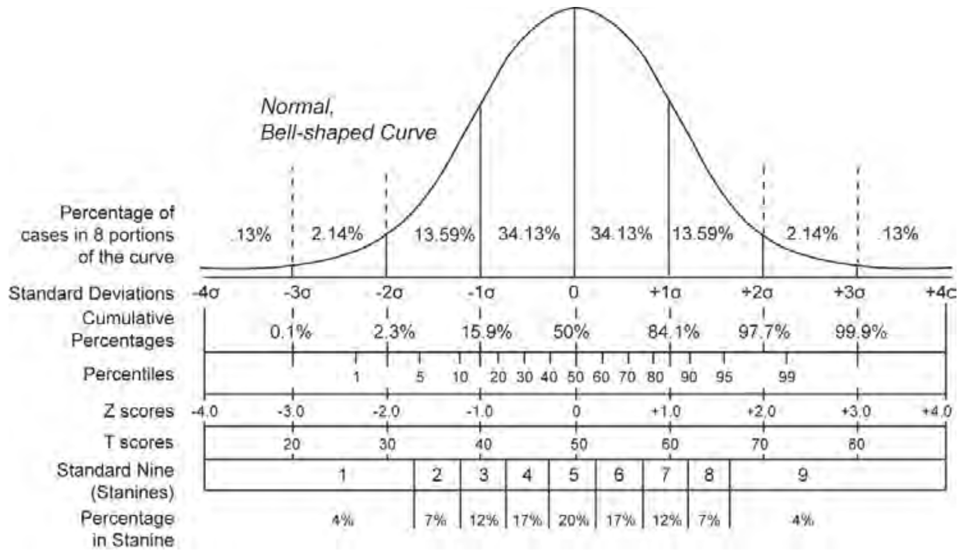
8. **Standardize the Results to Standardized Z-Scores Where the Mean Is Equal to 0 and the Standard Deviation Is One.**
9. **Sum Results:** Water Available (*2) + Water Stress Index (*2) + Water Quality.
10. **Model Requirements:**
    a. Model input. The primary model input is the sum of the Z-scores for water availability and the water availability index.
    b. Value Function.
        (1) The value function uses a single equation that measures the returns to scale of the attribute's score and returns the value of an installation's facilities. The curvature of the function is determined by TABS and coordinated with Army Environmental Command (AEC) SMEs.
        (2) The maximum value of 10 is given to the installation with the greatest amount of water available.
        (3) The minimum value of 0 is given to the installation with the lowest amount of water available.
    c. Model output.
        (1) The model converts the water resource score to a value for the installation.
        (2) Scores are normalized on a scale of zero to 10 based on value function.
        (3) This value function shows a linear relationship, which equates to constant returns to scale. The function implies that every additional water increment has the same value as the prior increment.

Reference: Roy et al. Directorate of Public Works (DPW), Environmental Section, Permits, Rad 303 (d) dataset.

C.2 Standardization of data

The z-score, standardized score (Figure C-1), and normalized score are synonymous scores for the number of standard deviations an observation or datum is above or below the mean. A positive standard score indicates a datum above the mean, while a negative standard score indicates a datum below the mean. It is a dimensionless quantity obtained by subtracting the population mean from an individual raw score and then dividing the difference by the population standard deviation.

Figure C-1. Distribution of standardized scores.



Source: Standard Score (2014).

C.3 SIRRA method for downscaling data

SIRRA is a dataset created by a team at CERL and the Land use Evolution and Impact Assessment Model (LEAM) group at the University of Illinois. SIRRA was developed in 2004 as a method to easily understand critical issues that are facing military installations and the data were updated in 2013. SIRRA characterizes the area surrounding an installation on 10 themes: (1) air quality, (2) airspace, (3) energy, (4) urban development, (5) threatened and endangered species, (6) location, (7) water, (8) economy, (9) quality of life, and (10) transportation. Within those 10 themes are 56 separate regional indicators that are categorized by sustainability vulnerability (e.g., very low vulnerability, low vulnerability, moderate vulnerability, vulnerable and high vulnerability). Using GIS analysis, the SIRRA methodology is then able to combine and rate indicators and develop sustainability vulnerability for military installations. These ratings are related to the data from the counties and watersheds in which the installations lie, rather than being ratings for the installations themselves. Taken together, these indicators "can aid in identifying potential issues that should be considered when stationing, base realignment and mission sustainment decisions are made. This information can also inform installation sustainability planning" (Deal 2013).

For datasets at the county level or hydrologic unit code (HUC) level, the SIRRA methodology was applied to produce data in this analysis. A model

developed in this work was used to determine the percentage of an installation that was located inside of each spatial unit. That percentage of coverage was then multiplied by the score for that spatial unit and the results were then summed. This method was used for this water availability analysis.

C.4 Supporting metrics for Water Quantity

C.4.1 Water quality index

C.4.1.1 Justification for using TMDL as water quality stand-in

The TMDL was selected as a threshold of water quality for two reasons:

1. **TMDL thresholds affect installation capacity**. When a waterway is classified as impaired, restrictions are placed on discharges into the waterway. Installation training capacity may be reduced so as to not discharge pollutants into waterways. Alternatively, an installation may have reductions in other support activities (such as clothes washing), as it might be limited in the temperature of water it releases.
2. **There is no current national water quality measure**. TMDL presents a narrow vision of water quality and excludes measures such as source water condition for drinking water systems, contaminated sediments, ambient water quality, urban runoff, or agriculture runoff potential. These variables were included in the USEPA Index of Watershed Indicators (USEPA 1999), which provided a holistic perspective on the water quality of regions. Initially released in 1999, the data have not been updated since. Because there is no indication that the data will be updated, a less robust measure of water quality was selected (Deal 2013).

The Impaired Water Model (Figure C-2) combines the point, line, and polygon data on impaired waterways that exceed TMDL from the RAD_303d dataset from the USEPA to calculate what percentage of an installation contains impaired waterways. Additionally, the analysis calculates the percentage of land within the surrounding half mile that is considered impaired.

The rad_303d dataset includes point, line, and polygon features that represent areas of impaired water. Five-foot buffers were added to the polyline and point data to convert it to polygon. A 5-ft amount was selected as it provides an approximation of the width of some rivers, but it is not meant to represent the exact amount of space covered by each type of impaired waterway. With the point and polyline data converted to polygon,

all three data were merged into a polygon feature class. This dataset was then clipped to the Army installations to determine the extent of the installation affected. Additionally, installations may not have impaired waters on their installation, but there may be waterways in the surrounding region that are considered impaired. As a result, the amount of impaired waterways within 0.5 miles of an installation was determined, as was water outputs from the installation that may expand the TMDL area. A composite score for each installation was created by using:

$$4A + 2B + 3C + D$$

where:

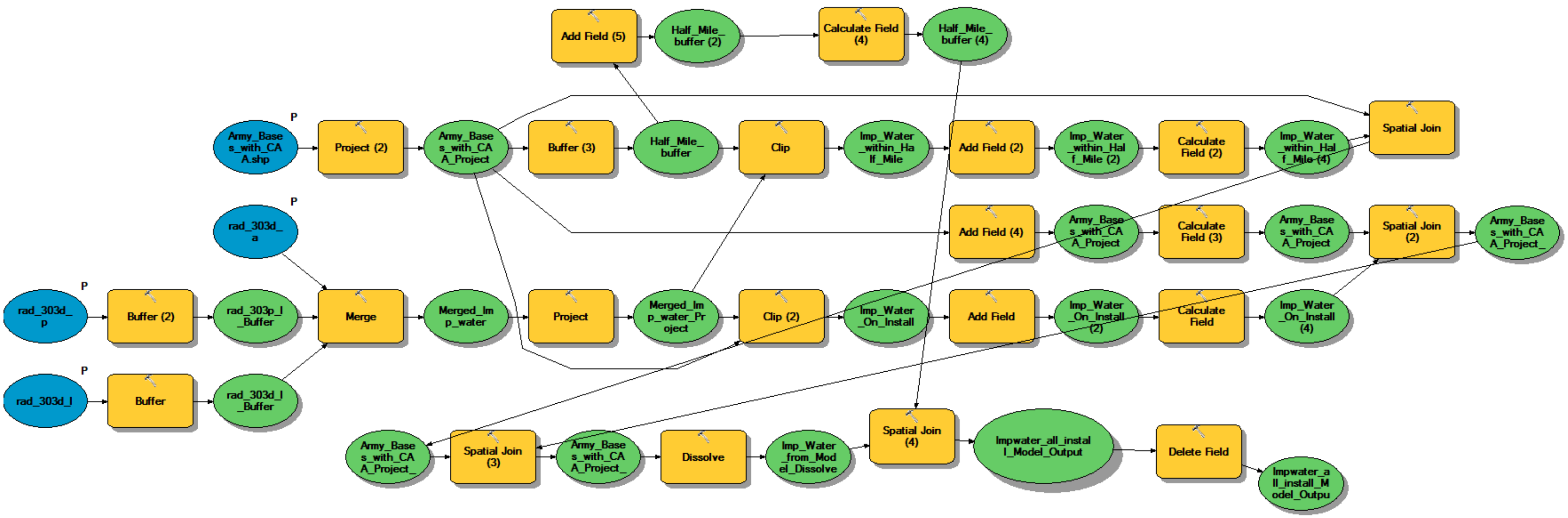
A = Acres of impaired water on an installation
B = Percentage of the installations' land covered by impaired water
C = Acres of impaired water within a half mile of the installation
D = Percentage of the acres within a half mile of the installation covered by impaired waters.

These results were then standardized.

C.4.1.2 Model inputs for Water Quantity index tool

Figure C-2 shows a flowchart representation of the Impaired Water Dataset (RAD_303d) from Data.Gov Installation boundaries.

Figure C-2. Impaired Water Model combines the point, line and polygon data on impaired waterways from the USEPA RAD_303d dataset to calculate what percentage of an installation contains impaired waterways. Additionally, the analysis calculates the percentage of land within the surrounding half mile that is considered impaired.



C.4.2 Water quantity metric

The information used in the 2005 BRAC analysis is over a decade old (for FY01-FY03). Two factors drove the decision to reference the older data—a low response rate from case study installations and a lack of comparable data.

- Question 826 of the Military Data Call regards average daily water use. The Army Water and Energy Reporting System (AEWRS) database is an enterprise system used to report annual energy and water consumption and tracks installation water. AEWRS tracks total water consumption by installations by quarter (AEWRS 2014). However, the analysis used in BRAC 2005 was based on average daily water use, which is the average of each day's water use and is able to better account for seasonal variations in water use that may stress water supply.
- Question 825 of the Military Data Call, regards the sources of an installation's water. This is not tracked through AEWRS, and therefore the only way to obtain updated information is by querying individual installations. Furthermore, the use of the data from BRAC 2005 enabled this work to demonstrate how installation scores shift with the new analysis.

C.4.3 Projecting water demand in 2050 at county level

C.4.3.1 Future water consumption stress *methodology*

Current stationing decision analysis does not consider water consumption stress (either current or future) within a region. As stationing efforts may exacerbate a region's water consumption stress in the future, an index for future *Water Consumption Stress* was developed. This Future *Water Consumption Stress* Index parallels the *Water Consumption Stress* Index developed for the current period and is used in the proposed MVA analysis (see Section 5.2.1.2). This *Water Consumption Stress* Index can be used in the *Environmental Elasticity* MVA attribute.

C.4.3.2 Future water consumption stress *data source: ICLUS County population projections*

This analysis of future water consumption stress assumes that per capita water use in each county will remain the same for domestic and public water supply sectors. The 2005 National Water Use Information Program data (USGS 2014) were combined with county population projections from the USEPA-developed ICLUS (Bierwagen and Morefield 2014) developed for the A1 emissions scenario.

C.4.3.3 Future water consumption stress data source: Electricity generation forecast

To generate future water withdrawal rates, future thermoelectric water withdrawal was estimated. Electricity generation projections for 2011 to 2040 provided in Table 96 of the 2014 Annual Energy Report were used to project future thermoelectric water withdrawals (U.S. Energy Information Administration 2014, 96). Their projections were provided at the Electricity Market Module (EMM) region level, which are accounting units developed by the EIA and relate roughly to the North American Electric Reliability Corporation (NERC) regions. In the continental United States there are 13 EMM regions of various sizes.

C.4.3.4 Calculation method: Future water consumption water stress

Following the methodology of Roy et al. (2012), water withdrawal data in 2005 were forecasted to 2050 using a business-as-usual projection. Public supply, domestic supply and thermoelectric water withdrawals were presumed to increase in the coming century. The factors of irrigation, livestock, self-supplied industrial, mining, and aquaculture were presumed to remain constant as the withdrawal levels have not changed significantly from 1970-2005. As a result, 2005 withdrawal levels were used.

Water withdrawals in the public and domestic sectors are expected to relate to population growth. On the assumption that per capita water use in each county would remain constant, the growth in these sectors was forecast using county population projections for the A1 scenario from the ICLUS dataset (Bierwagen and Morefield 2014).

A future electricity forecast using electricity generation projections for 2011 to 2040 from the EIA (U.S. Energy Information Administration 2014, p 96) was developed to generate future thermoelectric water withdrawal forecasts. Linear regression was used to forecast the annual EIA forecasts to 2050 for each EMM region. It was assumed that future electricity generation would occur in counties that currently produce electricity because they have pre-established infrastructure. The current percentage of the EMM's total electricity generated in each county was determined and then that percentage of future electric generation was applied to that county to generate county level forecasts. For example, if a county produced 27% of the electricity in the region in 2005, it was assumed that they would also produce 27% in 2050.

The following metrics were then calculated for both 2005 and 2050:

1. *Extent of development of available renewable water*: (Total freshwater withdrawal (2005) / total available precipitation)*100 [percent].
2. *Susceptibility to drought*: Available precipitation (P-PET) in summer months (June, July, August) – water demand (e.g., irrigation, thermoelectric) in summer (June, July, August) [in inches].
3. *Groundwater use*: (Groundwater withdrawal / total freshwater withdrawal) *100 [percent].

The water demand in 2050 was calculated using the following steps:

1. Download population data at the county level and project future population.
2. ICLUS A1 population projections (http://catalog.data.gov/dataset/iclus-v1-3-population-projections were used.
3. Estimate population change from 20010 to 2050 and 2070 at the county level: Population in 2050 (county) = population in 2000 × (1 + mean annual growth rate) ^50.
4. Calculate the percentage of population served by the public water supply and by the domestic water supply using 2005 figures from USGS Estimated Water Use in the United States.* Presume that these percentages remain constant and calculate values for 2050 and 2070.
5. Estimate increases in water withdrawal:
6. Increase in municipal withdrawal (2050-2005) = (Population in 2050 – population in 2005) × per capita water use (2005).
7. Increase in domestic water withdrawal (2050-2005) = (Population in 2050 – population in 2005) × per capita water use (2005).
8. Repeat for 2070.
9. Estimate public supply and domestic water demand:
10. Public supply withdrawal (2050) = public supply withdrawal (2005) + increases in public supply freshwater withdrawal
11. Domestic withdrawal (2050) = domestic freshwater withdrawal (2005) + increases in domestic freshwater withdrawal
12. Determine counties with thermoelectric generation
13. Obtain "Electricity Generation by EMM Region and Source" from Annual Energy Outlook.
14. Sum the Coal, Petroleum, Natural Gas and Nuclear sources for each year.
15. Use a linear regression to develop forecast of total energy production in 2050 and 2070.

* 2010 figures have now been released, and provide a more current account of water use.

16. Join data to shapefile.
17. Select counties where "PC-Power" (thermoelectric recirculation, power generated, in gigawatt-hours) variable from USGS is greater than 0 (meaning that thermoelectric electricity was produced in 2005).
18. Determine the EMM region that a county is located in: Use a spatial join to join these counties (producing > 0 thermoelectricity) to the EMM regions. As some counties may be in multiple EMM regions, use the "have their center in" method for the join. Depending on the county shapefile used, it may be useful to clip the counties to the EMM regions.
19. Calculate the % of energy produced in EMM region by each county = PC-Power (County 1) / Sum of PC-Power for all counties in EMM region.
20. Presuming that the % of power produced by each county in the region remains constant, estimate the power produced by the county in 2011, 2050, and 2070. Calculate the % of energy produced in EMM region by each county * EMM Value for the year.
21. Estimate increases in power generation (2050 – 2005): Increases in power generation (2050 – 2005) = power generation in 2005 × % change (2050-2005)
22. Estimate increases in thermoelectric water withdrawal: Increases in thermoelectric withdrawal = Increases in power generation (2050 – 2005) × withdrawal per unit power generation
23. Estimate total thermoelectric withdrawal in 2050: Total thermoelectric withdrawal (2050) = Thermoelectric withdrawal (2005) + Increases in thermoelectric withdrawal (2050-2005)
24. Estimate total freshwater withdrawal in 2050: Total freshwater withdrawal (2050) = Municipal freshwater withdrawal (2050) + thermoelectric freshwater withdrawal (2050) + withdrawal from all other sectors (2005)

C.4.4 Future water stress: Limitations and assumptions of future Water Stress Index

1. Public supply, domestic supply and thermoelectric water withdrawals were presumed to increase in the coming century.
2. The factors of irrigation, livestock, self-supplied industrial, and mining were presumed to remain constant as the withdrawal levels have not changed significantly from 1970-2005; as a result 2005 irrigation withdrawal levels were used. The analysis conducted by Roy (2012) found that irrigation intensity (water use per-acre) did not show a correlation with climatic drivers. Shifts in agricultural water withdrawals may be affected by factors such as water rights, crops being irrigated, water availability, and

irrigation practices. As these factors cannot be easily determined at the national level, a close examination of the data indicates that there was a 52% increase in water use for the aquaculture sector. However, USGS explains that the increase is most likely a result of a change in the way that the estimations were derived rather than an increase in actual withdrawals, so the current values were projected into the future (Kenny et al. 2009).

3. Future electricity generation was presumed to occur in counties with existing plants as they have existing energy infrastructure. It was also assumed that the percentage of electricity produced in the EMM region by each county would remain consistent (i.e., if a county produced 5% of the electricity in 2005 they would continue to produce 5% in 2050).
4. It was presumed that future power generation will use cooling technologies that are similar to modern plants with closed-loop evaporative cooling, at 500 gallons/megawatt-hour. This presumes that there are no broad shifts toward low water use cooling systems such as dry or hybrid wet-dry cooling.

C.4.4.1 Calculating Water Stress Index

The Water Stress Index was calculated using the values derived above. The initial analysis focused on the continental United States and the horizon of 2005 and 2050; these data were readily available:

1. Download es2030774_si_007.xls (1.33 MB) from http://pubs.acs.org/doi/suppl/10.1021/es2030774. This is the supporting documentation from Tetra Tech/ Natural Resources Defense Council.
2. Calculate values for 2005:
    a. Water Use: Total Withdrawals (2005)/ Available Precipitation (in, 1934-2005)
    b. Summer Deficit 2005: Summer time deficit (in, 2050) – changes in Summer Deficit (2050-2005).
3. Update 2050 values with your forecasted data:
4. Develop index of Risk
    a. In their analysis, Tetra Tech and the Natural Resource Defense Council created a five category index for counties. Two of these variables, however, relate to growth in water withdrawals. As a result, an index with three categories was developed. An additional shift from the original Tetra Tech data was that this work created additional ranges in these values—where a county could have a score of 0, 1, or 2 as opposed to just 0 or 1.
    b. Development Extent:

(1) If Water Use < 20 = 0
(2) If water use is >20.1 and <45 =1
(3) If water use > 45.1 =2
(4) Groundwater Use
(5) Groundwater Use < 25, 0
(6) If Groundwater use > 25.1 and < 45 = 1
(7) If Groundwater use > 45.1= 2
(8) Susceptibility to Drought
(9) If Summer Deficit is > -5.9 = 0
(10) If Summer Deficit is
(11) If Summer Deficit is < -10 = 2.

C.4.4.2 Baseline water stress: Calculate the baseline water stress for CONUS counties.

1. Download supporting data to the Tetra Tech report from http://pubs.acs.org/doi/suppl/10.1021/es2030774. These data are for the timeline of 2050, but they can be calculated for 2005 as well.
2. Calculate the following variables:
   a. *Extent of development*: total freshwater withdrawal (2005) / available precipitation (1934-2005).
   b. *Groundwater use*: Groundwater withdrawal (2005)/ total freshwater withdrawal (2005).
   c. *Summer Deficit 2005*: Summer time deficit (2050) – Changes in Summer Deficit (2050-2005)
3. Normalize each variable.
4. Calculate a composite score for each variable:
   Groundwater Use *(-1) + Summer Deficit 2005+ Extent of Development

C.5 Sea Level Rise

C.5.1 Calculate SLR

1. Data Required: "SLR and Coastal Flooding Impacts Viewer" data from NOAAs Digital Coast (link as of 7/14: http://csc.noaa.gov/slr/data/).
2. Select the state and then the appropriate counties and select "SLR." To create a dataset that can be used to test the susceptibility of energy infrastructure to SLR, downloading all counties is required. When the data are downloaded, unzip them to a folder. The dataset is quite large (over 90 Gigabytes).
3. Shape file of Installation Boundaries

4. Shape file of Coast Line features (from U.S. Census)
5. Tidal Gauges (keyhole markup language [KML] from http://www.ndbc.noaa.gov/). Select the program filter of NDBC Meteorological/ Ocean and select "Get Observations by Program as KML"
6. Optional: State boundary data
7. Project all of your data to North America Equidistant Conic projection.
8. The equidistant conic projection was selected because this analysis is valuing distance calculations.
9. Concurrently, in ArcMap use "select by location" to select the installations that are within 40 miles of the coast. This analysis used the coastline data in the National Coastline dataset from the U.S. Census. While Coastline dataset is generalized, it was used to generate approximate distances from an installation to the sea at a far faster rate than using a dataset with higher precision. Export a new feature class.
10. The threshold of 40 miles was selected as it is a number that incorporates the regional dependency of an installation, while an installation may not be located on the coast, it may rely on coastal ports or regional coastal infrastructure for supplies. Forty miles is the distance used in the CESL tool to analyze USACE Civil Works sites' vulnerability to climate change. Additionally, this threshold is the distance threshold used in the ASIP that captures those who live off-base and commute and who may be adversely affected by rising seas and storm events. Finally, it recognizes the regional relationship of an installation, where an installation may depend on the surrounding community.

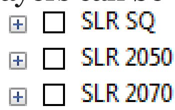
C.5.2 Determine installation proximity to tidal gauges

1. Prepare data
2. Use the KML to layer tool to create a feature class of the tidal gauge data.
3. Optional, but very useful - use a state layer to do a spatial join of the tide gauges with the states. This will provide state locations of the gauges (which is useful in the next step).
4. Visit the Sea Level Change Curve Calculator http://www.corpsclimate.us/cca-ceslcurves.cfm?gauge=8729840, which lists all of the tidal gauges that have SLR projections. Check the list of tidal gauges against the list on the site. If the gauge appears on the site, note "YES" in the "compliant" field.
5. Use "select by attributes" to select the gauges that are compliant. Export this as a new feature class. Open the attribute table and export this table as a *.csv or text file.

6. Calculate SLR: *NOTE: if a national dataset is NOT being made for energy analysis, complete Step 6 first to determine only the gauges closest to an installation to determine the expected amount of SLR there*
7. Open the table of compliant gauges in Excel. Sort these gauges based on the state.
8. Return to the Sea Level Change Curve Calculator (http://www.corpsclimate.us/ccaceslcurves.cfm?gauge=8729840) and select the appropriate gauge. Copy the data for 2050 and 2070 for each gauge (low, intermediate, and high). The entire row can simply be selected and copied to Excel. Ensure that your column headings do not include spaces and do not start with numbers. An example heading is "Y_2050_SLR_I" meaning Year 2050 Sea Level Rise Intermediate Projection
9. In a new column use the ROUND function to round the intermediate forecasts for 2050 and 2070 to the nearest integer. As the NOAA sea level rise data are available only in feet, this is the way to modify the expected SLR to fit the NOAA data.
10. Save file as an .XLS (example: SLR_2050_2070_Tide_Gauge)
11. Calculate SLR per installation:
12. Using the feature class of installations within 40 miles of the coast, use the near tool in ArcGIS to generate the distance from installations to the *nearest* tidal gauges. The near tool modifies the input feature class (installations), but only adds the NEAR_FID and NEAR_DISTANCE. Join the Installations and Gauges on the NEAR_FID field.
13. Join the SLR_2050_2070_Tide_Gauge Excel file to this.
14. Export the results of the join as a new feature class.
15. Match calculated SLR levels with NOAA SLR GIS data.
16. Join SLR_2050_2070_Tide_Gauge to the tide gauge feature class.
17. Label the tide gauges with the rounded values for 2050 and 2070. A label expression such as "SLR 2050:" + [Y_2050_SLR_I_R]+ "\n"+ "SLR 2070:" + [Y_2050_SLR_I_R] will place the SLR rise projections for 2050 and 2070 on separate lines and increase readability.
18. Working clockwise (starting with Maine) consult the tidal gauges present in each zone and add the appropriate layer for each time horizon. Add both the "low" and "slr" layers. For the Status Quo, select "0 feet of SLR."
19. If the zone does not have any gauges on it (OR_MFR, CA_MTR1, FL_MLF2 and FLMLB), use the measure tool and measure from the edge of the feature to the nearest gauges on either side. Select the projection from the nearest gauge.
20. The June 2014 analysis found only one instance where there were differing local SLR projections for gauges in the same zone. For the Massachusetts

zone, the Boston Harbor gauge forecasted 0 ft of SLR in 2050, while the rest of the zone was forecasted as 1 ft of SLR.

21. Once two features from the same year have been added to the map, group layers can be created. These groups will help to organize by time frame.



22. Create the dataset
23. Once the SLR projections have been added for the entire United States for each of the three time periods merge the files from each planning horizon together. In there will be three files: SLR_National_2070, SLR_National_2050 and SLR_National_SQ.

C.5.3 Final steps to calculate the SLR set

1. Using the projected sea level rise for each installation, bring the appropriate levels of SLR rise into the map from the NOAA data. Ensure that the ZONE NAME_slr_AMMOUNTft is brought in, rather than the ZONE NAME_low_AMMOUNTft Create group layers for Status Quo (SQ), 2050 and 2070. Once all data are in the map, navigate to Geoprocessing > Merge. For the input files select (using shift key) all of the layers for that particular year. Name the output something like "SLR_2050." Repeat and do for all three time horizons.
2. Next create a "low-lying areas" file for each of the time horizons. These low-lying areas are places that are expected to flood. Use the same processes as above, but bring in the ZONE NAME_low_AMMOUNTFort

C.5.4 Lost land to SLR and storm surge

The Lost Land Model determines the coastal inundation levels currently, in 2050, and 2070. This provides an estimate of the amount of land that an installation may lose as a result of climate change. The output produces a feature class with the amount of land expected to be lost for each of these horizons. As the total installation area reflects the total area within the installation, users of the output data should calculate [Installation Area M2] – [Lost Land SQ] to determine the amount of installation land currently not covered by water. The map of Aberdeen Proving Ground (Figure C-3) demonstrates how a significant portion of an installation can be covered with water currently. The Lost Land Model has three parts:

1. The *Parent Model*, which connects the two child models and calculates the amount of total installation land lost.

Figure C-3. The installation area of Aberdeen Proving Ground extends into the water. As such, the SQ coverage should be subtracted from the total installation area. The red line indicates the boundary of the installation.

2. The *Select SLR Model*, which clips the SLR extents to the installation area.
3. The *Lost_Land_Sp_Jn*, which takes the clipped SLR extents produced in the previous model and joins it to installations to produce the sum of the total amount of land lost.

C.5.5 Lost community infrastructure to SLR

The lost infrastructure model estimates the amount of community infrastructure located a yard of where SLR may rise.

1. Community infrastructure:
   a. Determine infrastructure that will be destroyed by SLR, storm surge and inland flooding. The following layers were selected from the HSIP Gold dataset: All places of worship, blood and organ banks, colleges and universities, daycare centers, emergency medical service(s), fire stations, hospitals, law enforcement, libraries, nursing homes, public schools, solid waste landfills, urgent care facilities, and veterans' health.
   b. After ensuring that each layer had X,Y coordinates the layers were exported from ArcGIS and opened in Excel. At that point extraneous fields were removed and the following were preserved for each layer:

Name, North American Industrial Classification System (NAICS) Code, NAICS description, X, Y, and Identify.
   c. The data from the individual layers were combined into a new sheet, which was then imported into ArcGIS as an event layer. This was exported as a feature class.
   d. Select the features that are within 40 miles of installations and create a new feature class of these “local” installations.
   e. As this is point data, apply a buffer of 30 ft to estimate building size.
2. SLR and Storm Surge: To increase performance the SLR and storm surge data were clipped to include a 40-mile radius around installations.

C.6 Variables used in renewable energy analysis

The variables used in the renewable energy analysis are: Installation rankings of Resource Abundance (access to a renewable resource, development resources, and financing that is economical and allowed according to regulations), Mission Compatibility, renewable energy potential, and energy consumption.

C.6.1 Resource Abundance, economic and regulatory environment, financial incentives

Resource Abundance, economic and regulatory and financial incentive values are based on the total renewable resource, state and regional regulations. Specific factors for this analysis were:

1. *Local and regional energy prices*. Areas with higher electricity prices may develop more renewable energy resources. Higher market prices for electricity allow higher cost technologies, such as renewables, to compete in the market.
2. *Regulatory incentives*. Federal, state or local programs may offer low cost loans, grants, tax incentives or other assistance to reduce capital expenditures and operational costs. Renewable portfolio standards and net metering also provide incentives by allowing facilities to sell energy back to the utility provider.
3. *Location*. Proximity and access to high voltage transmission lines.
4. Financing. Available funding.
5. *Developable land*. Land availability and suitability.

C.6.2 Mission Compatibility

Mission Compatibility assesses the overall impact of an energy project on an installation's mission requirements and the feasibility of the energy project. The rating was initiated by the FY10 National Defense Authorization Act, Section 332, reporting requirement that holds installations accountable for assessing and rating the Mission Compatibility of renewable energy from solar, wind, geothermal, biomass, and GSHP technologies. Installations were asked to rate the technology's compatibility with the various missions of their installation. The ratings are as follows:

- Red = Siting is incompatible
- Amber = Interferences exist, but can be mitigated
- Green = Siting is compatible with little to no interference.

C.6.3 Renewable energy potential

The renewable energy potential data are also derived from the same survey required by the FY10 National Defense Authorization Act (Section 332 reporting requirements). Renewable energy potential for each technology was estimated in terms of annual energy potential measured in million British thermal units (MMBtu).

C.6.4 Energy used on site

C.6.4.1 Summary

Onsite energy use data is derived from the Installation Status Report- Natural Infrastructure (ISR-NI) energy security question, MS 413-9: *What percentage within the last fiscal year of total onsite (privatized and non-privatized) base energy consumption does internal/onsite production meet?*

The renewable energy question, MS 414-1, could also be used: *What percent of total installation energy consumption is produced onsite from renewable energy sources?*

For the case study installations, these two values were consistent or the same. Both questions are offered as recommendations for inclusion in cases where one category may not be properly documented, but the other is.

C.6.4.2 Data source

FY12 Annual Energy Management Report by the Office of the Secretary of Defense, Installations and Environment (ODUSD I&E): http://www.acq.osd.mil/ie/energy/library/FY.2011.AEMR.PDF

AEWRS: http://army-energy.hqda.pentagon.mil/reporting/aewrs.asp

Installation Status Report for Natural Infrastructure (ISR-NI): https://isrtrain.hqda.pentagon.mil/isr/isrmainako/natural/NI_worksheets.html

C.7 Justification of renewable energy attribute and methods for analysis

The goal of this analysis is to quantify the energy security of an installation by measuring the potential for onsite renewable energy production that is sustainable and adds redundancy to the electrical power systems and/or heat generating systems.

Supply vs. Demand on the Installation is calculated as ($A_1 \div A_0$) and credit for purchasing or producing renewable energy is expressed as (A_2), where:

- A_0 = Total MMBTU of energy consumed (2013 annual data available from AEWRS or AEMR)
- A_1 = Total MMBTU potential (solar + wind + biomass + geothermal + GSHP); from AEMR/National Renewable Energy Laboratory (NREL)
- A_2 % Renewable energy purchased or produced onsite (from ISR-NI Energy Security question MS413-9 and ISR-NI Renewable Energy question MS414-1)
- (B_0) = Sum of Resource Abundance (AEMR 2013)
- (C_0) = Sum of Mission Compatibility (AEMR 2013).

The following formula was used to determine the renewable energy potential for installation energy security: $\frac{A_1}{A_0} + A_2 + \frac{B_0}{3} + \frac{C_0}{3}$, where the indicator is the Infrastructure Vulnerability metric.

C.8 Variables used in Infrastructure Vulnerability metric

The variables used in Infrastructure Vulnerability metric are: electricity transmission and distribution lines, substations, historic wildfires, hurricane storm paths and SLR.

C.8.1 Susceptibility to natural hazards variables

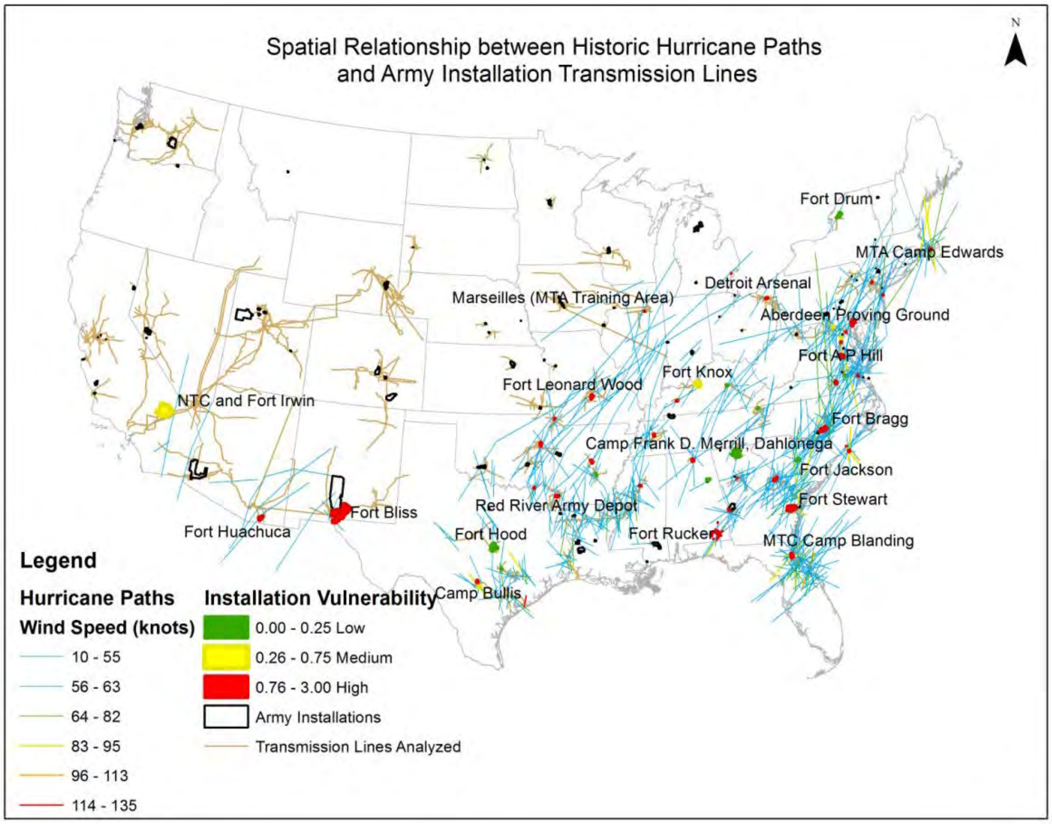
Storm-caused transmission outages cost U.S. utility companies and users around $270 million per year based on survey data obtained over 81 major storm events and 14 utility company respondents (Johnson 2005). The effects of hurricanes include strong winds, storm surges, flooding, tornadoes and riptides, which damage cities, infrastructure, and the environment several miles inland. Increases in sea surface temperature (due to climate change) of 1 °C could increase the peak wind speed of a tropical cyclone by 5% (Bjarnadottir et al. 2013). Additionally, the frequency of hurricanes may increase. If carbon dioxide levels double, hurricane frequency can increase by 6% (Bjarnadottir et al. 2013). Figure C-4 shows further evidence of hurricane impacts on energy infrastructure.

C.8.2 Hurricane vulnerability

Thirty-eight of the 157 Army installations analyzed have transmission lines previously at risk of damage from historic hurricanes (Figure C-4). The results indicate spatial correlation. In a re-analysis, only more recent hurricane data will be used (1970 to the present as other studies have done) to show recent trends and to incorporate climate change projections to determine at-risk regions. Based on historic evidence, Fort Bragg is at the greatest risk to hurricanes, as calculated by:

Six of the six transmission lines powering a portion of the base have been in historic hurricane paths.
Transmission lines affected by storms/total installation transmission lines.
6/6 = 1.
1 * Number of storms (3) = 3.
Vulnerability Score = 0.

Figure C-4. Results of spatial intersection of hurricane paths and transmission lines.



C.8.3 SLR and electricity generation

According to this analysis no currently operating Army-related (within the installation or along the provided transmission lines linked to installations) substations or electric generating units are threatened by 2050 or 2070 SLR scenarios.

The 2050 SLR national infrastructure results are:

- 26 of 49,414 (0.05%) substations currently in service (current as of 2013) will be affected by 2050 sea levels.
- 59 of 20,284 (0.29%) total electric generating units are within the 2050 SLR boundaries.

The 2070 SLR national infrastructure results are:

- 89 of 49,414 (0.18%) U.S. substations currently in service are within the 2070 SLR boundaries.
- 69 of 20,284 operating electric generating units are at risk to sea level inundation.

C.8.4 Total susceptibility to natural hazards

Table C-1 lists the MVA scores as they relate to susceptibility to natural hazards.

Table C-1. MVA score: Susceptibility to natural hazards.

Installation	Vulnerability Score (fires)	Vulnerability Score (storms)	Total Vulnerability Score	Average Vulnerability	MVA Score
Fort Bragg	0.00	0.0	0.00	0.00	10.00
Fort Drum	0.00	0.0	0.00	0.00	10.00
Fort Riley	0.00	0.0	0.00	0.00	10.00
Fort Bliss	0.15	0.0	0.15	0.08	9.93
Fort Lewis	0.25	0.0	0.25	0.13	9.88
Fort Wainwright	0.63	0.9	1.53	0.76	9.24
Schofield Barracks Military Reservation	0.00	3.0	3.00	1.50	8.50

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14. ABSTRACT

In the decades to come, climate change is expected to impact the Army's costs, its abilities to train and maintain the force, and its mission capabilities. These potential climate change impacts need to be considered in the Army's stationing/restationing analysis process to ensure that future decisions concerning locating and relocating Army Forces are optimized to minimize costs while maintaining the ability to effectively train, maintain and deploy forces.

The Center for Army Analysis (CAA) is part of the Army Stationing Process that is responsible for analyzing and recommending possible stationing scenarios to Army leadership. In the past, environmental considerations were not well defined and were treated in a qualitative rather than quantitative manner. As a result, CAA recognized a need to focus on environmental issues, particularly the effects of climate change on future stationing actions. This study was performed to identify and recommend possible improvements to the Army's stationing/restationing analysis process, specifically, by including climate factors in the stationing analysis process to enable a more complete modeling and cost analysis.

15. SUBJECT TERMS
Center for Army Analysis (CAA), climate change, planning, military installations, stationing

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